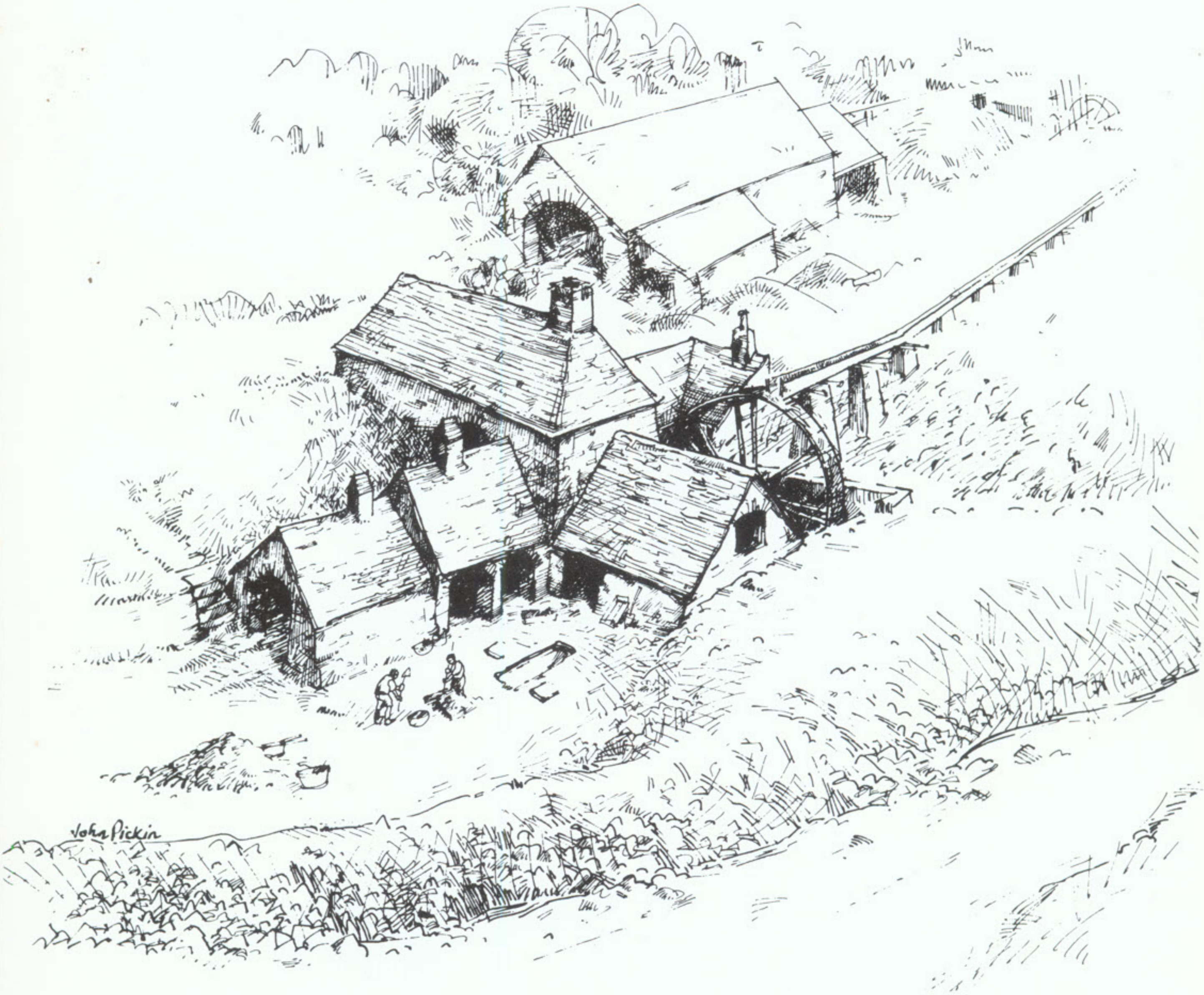
HISTORICAL METALLURGY

ISSN 0142 3304

Journal of the Historical Metallurgy Society volume 16 number 2 1982



Abbey Tintern Furnace

Journal of the Historical Metallurgy Society

JHMS 16/2 1982

Published by the **Historical Metallurgy Society** which is affiliated to the **Metals Society**

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Cover illustration

Abbey Tintern Furnace (SO 513002) has been extensively excavated through the combined efforts of the Gwent County Council, the Manpower Services Commission, the Welsh Development Agency and the Forestry Commission. The excavation was directed by John Pickin (who produced this conjectural drawing) and substantial remains were found of the furnace and associated wheelpit together with foundation evidence of the cast, blowing, bridge and charcoal houses.

Designed and produced by Roy Day FSIAD and IBM Composer set by Kathleen Taylor

Printing arranged by the Metals Society, 1 Carlton House Terrace, London SW1Y 5DB.

Herbert Henry Coghlan 1896-1981

We dedicate this issue to the memory of H H Coghlan whose contribution to the study of archaeometallurgy is well-known. His wide range of interest is shown by the papers we received from eminent colleagues and friends such as Prof Pittioni of Vienna, Drs Matteoli and Storti of Italy and Prof Selimkhanov of Baku.

We regret that it was possible to devote only one issue to the memory of such an eminent pioneer. We do however, invite further contributions for publication in later issues.

H H Coghlan, MIMechE, FSA

Our distinguished Honorary Member H H Coghlan died on the 27th June aged 85. He was born into a landowning family near Dublin. While his father was Irish his mother was English and came from Hurstbourne Tarrant in Hampshire.

In his youth he took part in the usual country pursuits and he became an excellent golfer as well as a keen mountaineer. But this was the early days of the automobile. From the age of 12 he drove cars on the family estate and maintained, repaired and even modified them to his own very personal ideas. It is not surprising to us, although it was to his father, that he announced his intention to become an engineer. He started on a course at Trinity College, Dublin. But left before completion to enter the Dublin Railway workshops. So started a brief but intensive career in railway mechanical engineering.

In the 1920s he joined the Burmese Railways. During this time he became a member of the Institute of Locomotive Engineers and an Associate Member of the Institute of Mechanical Engineers. While on leave from Burma he met his future wife while climbing in the Pyrenees. They both returned to Burma and were married in 1923. Unfortunately the climate did not suit his wife and they returned to England in 1926. From the 1930s onwards he worked with a firm of consulting engineers on a contract for the Indian State Railways placed with Krupp's of Essen and Henschel of Cassel, and spent much time in Germany.

He returned to England before war broke out and was given a job as an inspecting engineer on aircraft for the Ministry of Aircraft Production at Farnborough. No doubt his great perfectionism served this country well in what for him was a completely new field.

From 1923, before he went to Burma, he lived in Boxford near Newbury, next door to Harold Peake, President of the Royal Anthropological Institute. This Institute and the Anthropological section of the British Association had set up, in 1922, a Committee on Ancient Mining and Metallurgy which concerned itself with problems arising from the survival of primitive industries in developing countries and material from archaeological excavations. Peake, who had a reputation for spotting talent, at once saw the materials scientist in him and enlisted him on to his committees. In 1946 Coghlan took over the Honorary Curatorship of the Newbury Museum and so started a long association with Newbury and Berkshire which was to prove most fruitful. He was ably assisted by his wife Margaret who acted as his assistant, secretary and translator; she did much of the historical research required for the labelling of museum objects.

It was in the late thirties that Coghlan started contributing papers on archaeometallurgy to journals, such as Man, the Journal Royal Anthropological Institute, Antiquaries Journal, Archaeologia Austriaca, Sibrium and, eventually, to our own Journal. He was a pioneer in the subject and soon gained an international reputation.

He applied much of his time to reorganising the collection in the Newbury Museum and making it more representative of the history and natural history of Berkshire. Thus he was able to investigate thoroughly foreign items in the collection which formed the basis of many of his papers. But the Newbury collection was not sufficient to satisfy his appetite for knowledge about archaeometallurgy and a fruitful liaison started with the Pitt Rivers Museum, Oxford, where T K Penniman, I M Allen and Dennis Britton were occupied with similar problems, and with Humphrey Case of the Ashmolean Museum.

Resulting from these researches Coghlan was the first to produce a much needed book 'Notes on the Prehistoric Metallurgy of Copper and Bronze in the Old World', which was published in 1951 and which was followed in 1956 by another book 'Notes on Prehistoric and Early Iron in the Old World'; these opened up a new field. Both have become an authoritative work of reference to the archaeologist and are still widely used.

Coghlan retired from the chairmanship of the Ancient Mining and Metallurgy Committee of the Royal Anthropological Institute in 1963, the year the Historical Metallurgy Society was born. This was a coincidence which turned out to the good of the society. He continued his research work and we gained from his wide knowledge and advice.

H H Coghlan had great charm and warmth with a twinkle in his eye and a dry wit which was hidden behind a rather shy and retiring facade. He was most at home with mechanical things and was always eager to discuss archaeometallurgical problems, and on visits to his cottage one was inevitably steered to his workshop which was well equipped with apparatus for his metallurgical examinations.

He will be greatly missed by his friends and colleagues but his memory will live in the important contribution he made to archaeological science.

June 1981

R F Tylecote

The Archaeometallurgical Works of H H Coghlan

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Metallurgical notes on three Bronze Age implements found in the West of England

George Parker

L V Grinsell, whilst still the Curator of Archaeology in the City of Bristol Museum, wished to know the chemical composition of the metals of two flat axes in that museum, and in a double-edged tanged knife, or short rapier, in Wells Museum. When asked to obtain this information, the author sought and was given permission to cut specimens large enough for microscopical examination in addition to spectrographic, and microchemical analyses, the latter for major alloying elements.

Double-edged ,Tanged Knife, Wells Museum

This knife, shown in Fig 1, is recorded as found at Maesbury, 4 miles ENE of Wells. It is 152 mm long, and 25 mm across at its widest point, where the central rib is 13 mm wide and 2 8 mm thick. The weight is 49.95 gm. The knife is green-patinated in good condition and the hexagonal section of the blade is well-retained. This section had been formed by the slightly-tapered blade having been thinned down symmetrically on each side of the central rib to form the two cutting edges. The short, flat tang has no rivet hole for securing a handle, but very slight flanges, raised along its edges ,were probably intended to contribute to this purpose.

Fig 1 Double-edged Tanged Knife, Wells Museum

Of three rather-similar knives (but in less-good condition) in the Yattendon hoard displayed in the District Museum, Newbury, Berkshire (Nos Y14 – Y16 in a report published by H H Coghlan from that museum), one had a rivet hole through its tang. The Yattendon knives all showed lead contents exceeding 5% and this, in the context of the hoard of almost 60 artifacts, placed them into the late Bronze Age. By contrast, microchemical analysis showed the Maesbury knife to be of bronze containing 14% tin and only 0.3% lead. This composition caused Grinsell to accept the knife tentatively as being from late in the Middle Bronze Age (private communication). Semi-quantitative spectrographic analysis indicated levels of minor constituents rather higher than usual, with possibly 0.5% iron and 1% nickel.

V-shaped specimens were cut from one side of the tang and from the tapering zone on one edge of the blade, the depth of the cuts being about 5mm. The resulting two notches in the knife were virtually invisibly-restored by a technician in the City of Bristol Museum. (Similar restoration was applied to the two flat axes, after sectioning. Chemical analyses were made on the biggest microspecimens after all other tests had been completed.) The specimens were mounted in a cold-setting transparent plastic so that planes of the tang and the blade transverse to the long axis of the knife were polished, using a standard metallographic technique. The prepared surfaces were examined unetched and after separate etches, using hydrogen peroxide/ammonia, and alcoholic acid ferric chloride. It was possible to place diamond pyramid hardness indentations with a 2½kg load on the more substantial parts of the specimens, but to approach the cutting edge a microhardness test using the relatively-high load of 200 gm was necessary. Direct comparisons of standard and microhardness tests, where they could both be made indicated that the microhardness system inflated the standard values by 10-15 points.

The unetched specimens showed many grey inclusions which were initially taken to be of lead, so the low lead content came as a surprise. However, many inclusions in metal look grey and those seen here probably reflect the relatively-high level of minor constituents found spectrographically. It was seen that the slight flanging had been produced by a cold shaping operation, probably hammering, as the flange metal showed folding and cracking. A flowing orientation of the inclusions in the blade section was evidence of considerable working concentrated towards the cutting edge. The blade also showed a number of fine cracks, the longest extending about half-way through the thickness of the section. This crack had started from an alpha-delta eutectoid area which looked to be fragmented by cold-work. (In a forthcoming paper by Coghlan and the author, such shattering of alpha-delta eutectoid will be reported in a homogenised ancient 12.6% tin bronze, cold-rolled down to 50% of its original thickness). A crack is illustrated in Fig 2. The cracking had evidently helped corrosion penetration of the blade – in Fig 2, slip-plane corrosion can be seen adjacent to an apparent void from the other end of which the crack originated – the void was possibly originally an area of eutectoid. The peroxide/ammonia etch produced little additional information, save to make it rather easier to see that there was a substantial amount of alpha-delta-eutectoid present, and that there was no sign of dendritic, ie cast structure. The ferric chloride etch emphasised these points. In the tang the matrix was of twinned equi-axed grains showing some slip-banding indicative of cold-work, with islands of alpha-delta eutectoid and the grey unidentified inclusions (Fig 3) confirming a fully-worked metal with little trace of the original cast structure remaining.

The cutting edge showed much elongation of the grains and considerable slip-banding revealing a substantial degree of cold-working (Fig 4). Whilst it is not uncommon to find that ancient tin bronze tools have been fully worked in their production, the 14% tin content of the Maesbury knife seemed surprisingly high in such an artifact. Modern bronzes for cold-working usually have 7% tin as the upper limit.

The hardness values fitted in with the high tin content, being **HV2½** 137 in the tang and **HV2½** 140, just off the central rib of the blade. The microhardness test with 200 gm load applied very near the cutting edge showed $HV_{0.2}$ 262. This, allowing for the tendency of microhardness tests to read high, can be taken as about **HV2½** 250.

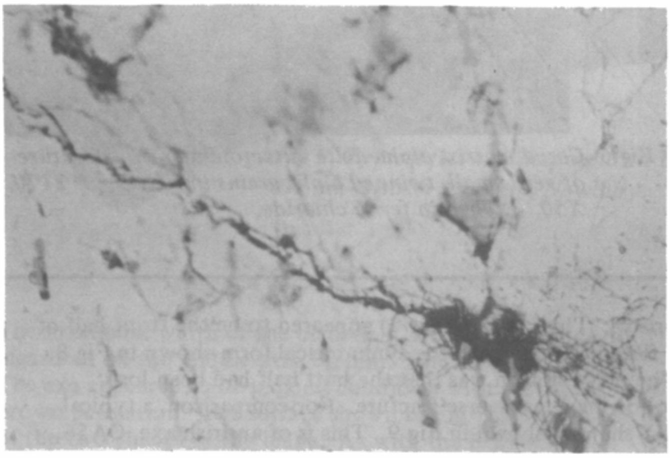

Fig 2 Crack and slip plane corrosion in cutting edge of the tanged knife, X350. Lightly etched in peroxide/ammonia

Fig 3 Twinned alpha-grains showing slip bands, alpha-delta eutectoid and grey inclusions in tang of tanged knife, X200. Etched in ferric chloride.

In an extensive investigation of the working properties of tin bronzes, R Chadwick (J I M **LXIV** No 1, 1939 p 331) obtained a hardness of HV 253 with a 14% tin bronze following a cold-rolling reduction of 50% . R F Tylecote in an experimental casting programme using stone moulds produced hardnesses of **HV2½** 224 in hammered edges of a rapier, the metal – a 13.6% tin bronze – of which had been homogenised after casting (Bull Hist Met Group, 7, No 1 1973, p 1). The Maesbury knife's maximum hardness accords well with Chadwick's and Tylecote's values and is well in excess of the figures (maximum, HV 164) quoted by Tylecote for other Bronze Age rapiers. Chadwick also shows that a tin bronze with HV 250 has a tensile strength of around 55 tons/sq in. Such values easily exceed those obtained on many Iron Age products (see ,for instance, H H Coghlan in 'Occasional Papers on Technology, 8, Pitt Rivers Museum, University of Oxford, 1956, pp 180-192). Skimpy use of metal and inclusion of several % of lead in bronzes of the Late Bronze Age suggest to the author that it was possibly the lack of good bronze stemming from a shortage of tin, rather than any immediate superiority of ferrous metals, that forced the move into the Iron Age.

Fig 4 Flowed structure with elongated slip-banded grains in cutting edge of tanged knife, X350. Etched in ferric chloride.

What might be called the core of the Maesbury knife is less hard than the cutting edge, and therefore would be less brittle. This is a good point in design since the blade should still be strong because it is thickest where it is softest, and there would be a reduced chance of the blade snapping in hard use.

One must admire the skill of the prehistoric craftsman who worked his intractable metal into this well-designed product. However, the cracks indicate that he took his metal almost to the point of failure. This suggests that a sort of Darwinian natural selection has applied with failures soon back into the melting pot, whilst successful tools remained in service, so having best chance of survival. Unusual circumstances could clearly alter this: the Yattendon hoard, previously mentioned, contains so many damaged or defective objects that Coghlan has reasonably surmised that they were collected for remelting. Presumably, the hoard survived because the smith who hid it, didn't!

II Flat Axe, F 2170, City of Bristol Museum

This axe, shown in Fig 5, was recorded in Trans Bristol & Gloucestershire Archaeo Soc **XXVII** Part II, 1904, p 329, as 'Flanged celt: 4¼ in long, 2 in across cutting edge, 3/8 in thick in centre; weight 7 oz; dark brown colour. Found many years since during operations connected with the widening of Bristol Bridge'.

Bristol Bridge is in the centre of that City. The flanging is very shallow indeed. The artifact is in good condition and shows no obvious sign of corrosion. There was no outer evidence of the means of manufacture – for example, no trace of a parting line that would have suggested a casting produced from a bivalve mould.

The experimental procedure followed that described above,

Fig 5 Flat axe, F2170, City of Bristol Museum

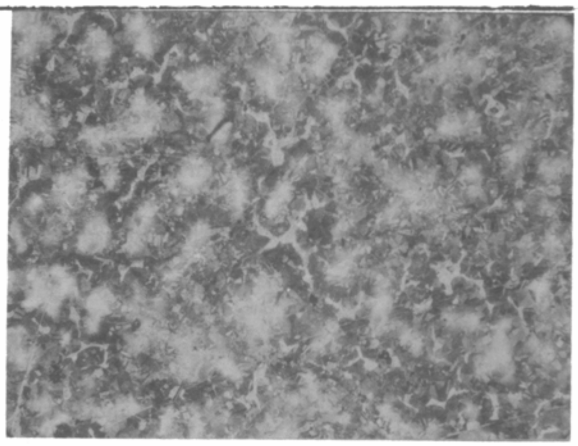

Fig 6 Cored matrix, alpha-delta eutectoid and sub-structure of very small, twinned alpha grains in flat axe, F 2170, X50. Etched in ferric chloride.

for the Maesbury knife. Wedge-shaped specimens were cut from the edge at the thickest part of the body of the blade, where working operations might be expected to have been least, and from the cutting edge, where greatest working was likely. Comparatively limited areas of alpha-delta eutectoid could be seen in the unetched microspecimens, together with some porosity particularly in the thick section. Etching clarified the visual information showing a rather-diffused dendritic structure, with very fine-grained, twinned, equi-axed alpha crystals superimposed (Fig 6). Such sub-structures are now associated with internal stresses arising during the cooling of a cast metal, with the temperature still high enough to allow relief of the consequent strain by the initiation of recrystallisation. R F Tylecote has noticed the same effect in the head of brass ingots (Private communication). The retention of this fine structure must imply that the artifact couldn't have been reheated after casting sufficiently for any growth of the very small alpha grains to have occurred. Such growth would be expected at any usual annealing or homogenising temperature.

The microstructure of the cutting edge specimen showed a flow or elongation towards the edge, revealing that cold-work had been applied to the edge, most likely by hammering, to sharpen and/or to harden it. The diamond pyramid hardness figures determined using a 1 kg load, supported these indications. The average of three HV_1 measurements on the thickest body section was 125 whilst, in the cutting edge section, readings getting successively nearer the edge showed **HV1** 168, 177 and 181.

Spectrographic analysis had shown copper and tin as the major constituents, confirming the metal to be a tin bronze. The levels of minor constituents were indicative of a reasonably-pure alloy. The tin content was determined later by microchemical analysis on a microspecimen and was 11.7%.

The shape of this axe suggests that it belongs to the early Bronze Age. Compositional factors such as the low lead content are in line with this. The microscopical evidence shows the axe to be substantially in the as-cast state, with cold-work used only on the cutting edge, leaving it fairly well-hardened.

III Flat Axe, F 3658, City of Bristol Museum

The provenance of this implement is given as '? Totterdown '. This indicates an area about 1 mile South of the centre of Bristol. This artifact (Fig 7) appeared to be the front half of a flared flat axe with the symmetrical form shown in Fig 8. The presumption was that the butt half had been lost following a transverse fracture. For comparison, a typical full shape is shown in Fig 9. This is of an Irish axe, OA56, in the District Museum, Newbury, and described by H H Coghlan ('MAN', July 1953, No 150).

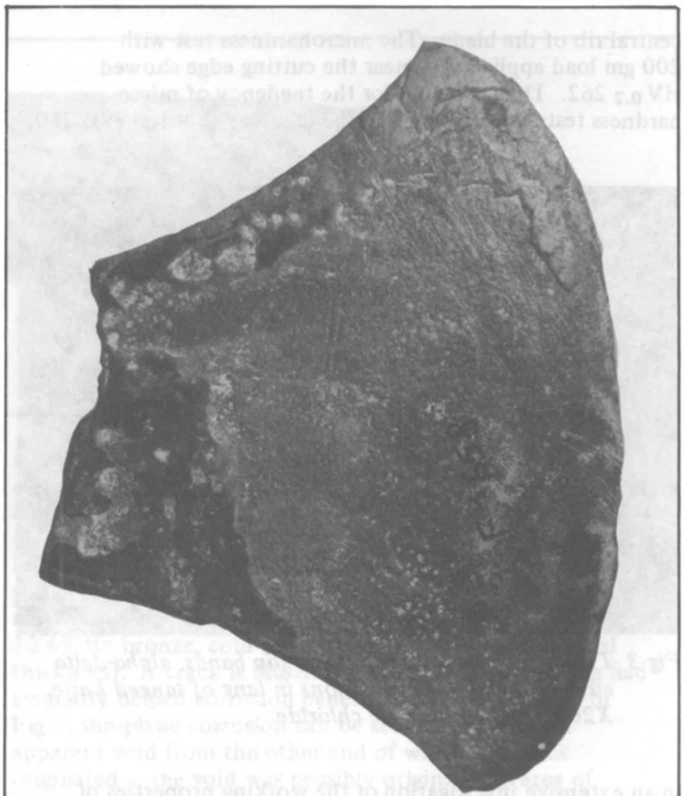

Fig 7 Flat Axe, F3658, City of Bristol Museum

Side view of flat axe, F 3658, to show its symmetrical section

Fig 9 Typical flat axe shape shown by OA56, District Museum, Newbury.

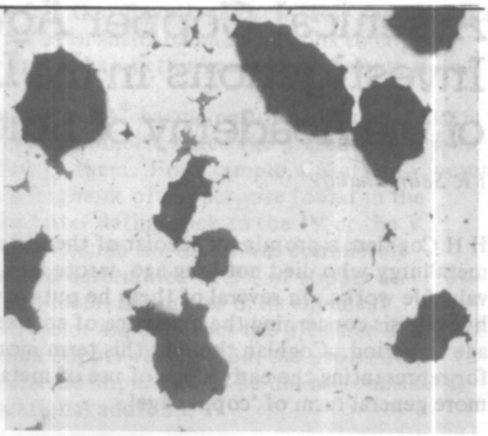

Fig 10 Gross porosity in body section of flat axe. F 3658, X50. Unetched.

The maximum width of the blade is 125 mm and the length measured on the middle axis, 90 mm. The weight is 449 gm. The axe appeared to be in good condition with greenish-brown patination. The surface shown in Fig 7 is the worse of the two cheeks of the blade. As with the F 2170 axe, there was no visible evidence of a parting line to reveal casting in a bivalve mould.

Specimens were taken from the cutting edge, and, on the assumption that about half of the implement had been lost, from a rear corner, as representing the least-worked zone. The experimental procedure was as for the two artifacts already described.

The microstructures observed were practically identical with those seen in F 2170 except in one important particular – the structure bounding the putative fracture was very porous indeed (Fig 10). The pores show the cusped shapes typical of interdendritic porosity in a cast metal. This unsoundness arising from bad casting, is an obvious source of weakness and supports the theory that a transverse fracture had occurred. This may have happened when the axe was being dressed after casting. However, this part of the blade would have required little doing to it, so failure more probably occurred when the axe was in use. Porosity was not evident in the cutting edge section where the structure showed a flow, indicating cold work had been applied there. Such forging can tend to close up pores but it is doubted whether it would have disguised the considerable unsoundness seen in the centre body section (Fig 10) which therefore was probably local rather than general throughout the casting. As already implied, the microstructure showed areas of alpha-delta eutectoid, in a cored matrix with a substructure of very small twinned alpha crystals. The cold-working process applied to the edge was probably hammering used to sharpen it and, possibly incidentally, to harden it.

The results of hardness tests were in line with the metallographic evidence. The indentations were carefully placed on the body section to avoid the porosity. The average of three such readings was HV_1 135. In the cutting edge section, the figures were HV_1 181, 191 and 197 as the edge was approached increasingly closely.

Spectrographic analysis showed the major constituents to be copper and tin, confirming that the metal is a tin bronze. Microchemical analysis later showed the tin content to be 11.8%. Minor constituents were at a level well above average.

This raises a question whether the high degree of porosity had allowed penetration of impurities into the metal, and that they then couldn't be removed by the preparation of the sample for spectrography. Spectrographers are of course, alert to the possibilities of contamination on specimens.

By contrast with the Maesbury knife which is a fully-wrought product, the two Early Bronze Age axes from the City of Bristol Museum are substantially in the as-cast state, save for some cold-work at the cutting edges. This limited amount of this forging, together with the symmetrical section of the blades indicate that the castings had not been made in open moulds. The author has not read of the discovery of any bivalve moulds of flat axe form. Casting by a lost wax process would be feasible and not leave moulds that might survive. However, that casting method might be too sophisticated to have been in use at such an early date. What type of mould was used therefore remains an unanswered question.

Acknowledgements

The author appreciates the permission given by L V Grinsell to cut specimens from the two Bristol axes, and by the late Dr F S Wallis, when still Hon Curator of the Wells Museum, for similar access to the Maesbury knife, and for having all three artifacts restored after specimen-cutting. As always, the author is grateful to former colleagues, and especially Mrs A M Sumner, AIL, AIM, for analyses and some hardness tests, and to the Lucas Group Research Centre for the remaining hardness determinations.

As in all his Bronze Age work over a period of thirty years, the author had the kind and unfailingly-courteous support and advice of the late H H Coghlan, MIMechE, FSA, FRAI, for long the Hon Curator of the District Museum, Newbury, Berks.

'I shall not look upon his like again'.

George Parker. Before his retirement George Parker worked with Dr Maurice Cook with the ICI Metals Division in Birmingham. Since then he has been active in the archaeometallurgical field and has collaborated on many projects with H H Coghlan. More recently his interests have tended towards the history of photography and he has been instrumental in establishing an exhibition of photographic equipment at the Museum in Newbury.

Arsenical Copper Age in H H Coghlan's works: and Investigations in the Laboratory of the Institute of History of the Academy of Sciences of Azerbaijan SSR

I R Selimkhanov

H H Coghlan, a prominent scholar of the history of ancient metallurgy who died not long ago, wrote a number of valuable works. In several of them he put forward a hypothesis concerning the existence of an arsenical copper age or period. Coghlan thought this term more correct for representing the early stage of use of metal than the more general term of 'copper age'.

In connection with the problem of the copper age and arsenical copper age or period it is pertinent to discuss the views of some scholars in the light of investigations carried out in the laboratory of the Institute of History of the Academy of Sciences of Azerbaijan SSR.

The Copper Age. It is well-known that the theory of the existence of a copper age was first raised at the International Archaeological Congress held in Budapest in 1876. The debates followed the statement that the chemical analyses of a few ancient metal objects found in Hungary revealed that they were made of pure copper. It was then that the theory of the existence of a copper age in Hungary became established.

V Pulszky[1] even published a special monograph about the copper age in Hungary in 1884.

In 1885 G Sittle[2] vigorously supported the assumption of the existence of a copper age in the past not only in the European regions but also in an extensive area of the Old World. He asserted that this hypothesis was proved by the results of supposedly precise chemical analyses which showed that humanity had used the tools made of pure copper before the appearance of tin bronze. Thus Sittle used the concept 'copper age' to represent a certain period in the history of mankind when only copper was known while other metals were discovered only later.

But when was the assumption of a universal copper age ie the period in the history of many regions of Ancient World, first put forward? It seems to date back to the year 1893 when M Much[3] published his work 'The Copper Age in Europe' in which he stated the existence of a copper age not only in Europe but in Asia too. By Europe he meant Austria, Hungary, Rumania, Yugoslavia, Switzerland, Germany, Denmark, Italy, the British Isles, France and certain other countries. He also mentioned the results of chemical analysis of the most ancient copper objects in which additions of other metals were absent, tin as well. The small impurity content was not considered significant although additional metals content in some cases amounted to few tenths of a percent. But the number of analyses of ancient copper mentioned by M Much was very limited and one cannot be sure of their precision.

Marcelen Berthelot's views[4] about the copper age are pertinent for the present discussion. According to Berthelot the existence of this period in the history of mankind was accepted by the archeologists and the use of tools made of pure copper ie without tin in copper, forms its essence. Berthelot was sure of the existence of this period in both Egypt and Mesopotamia. His assertion was based on the absence of natural tin resources, ie tin ore deposits ,in these regions. This meant that the tin necessary for tin bronze production had to be brought from faraway countries. In his opinion, this could have taken place only much later when commercial transportation from faraway countries had developed.

Thus, the ancient smelters in Egypt and Mesopotamia did not make tools only of tin bronze, but used pure, ie unalloyed, copper. That is why M Berthelot first wanted to determine the time when tin was still absent in these regions. As a test the most ancient finds that were supposed not to have any tin content in the copper, ie the copper age continued to exist, were subjected to chemical analyses.

Nevertheless, when the theory of copper age's existence in the Old World had become firmly established, some suspicions of its universal character, ie existence in many countries, were aroused. The doubts as to this being true were, on one hand, based on purely theoretical reasons and, on the other hand, they were supported by the empirical evidence obtained by the analysis of copper objects. The use of chemical analysis was developing in archeology and it helped to show that the most ancient copper finds really did not contain tin. But a number of them contained some other metal impurities. Thus it turned out that these finds cannot be classified as pure copper. It means they do not prove that the monument they were found in belongs to copper age or period. A brief account of these doubts in their chronological order is given below.

1913. G Obermeier[5] challenged the copper age's existence in Europe. He reasoned that stone and bronze tools were used side by side with primitive copper ones in an extensive area of Europe in the most ancient periods. Moreover, he suggests that the first use of metal by man begins at the end of the Neolithic. It is claimed that copper was really the first metal discovered by humanity, but the period of its use is so closely connected with the stone age, ie Neolithic, that it is impossible to consider the copper age as an independent period in the history of mankind.

Of interest is the fact that Obermeier's assumption is corroborated by a number of modern scientists ,especially H H Coghlan, with certain amendments.

In 1912-1922 a prominent historian, geochemist V I Vernadski[6] in his work first entitled 'An Essay of Descriptive Mineralogy', reprinted in 1955, also challenges the universal character of copper age theory. In his opinion, the theory of copper age existence is due to the frequent findings of copper tools. But the conclusion that there existed a copper age before the bronze age does not correspond to the factual date. Nevertheless, he thinks it unquestionable that there were some periods in the history of mankind when copper played a great role in the culture and was used in more or less pure state. In connection with Vernadski's assumption we ought to say that up to now the use of pure copper has been associated with native copper as the first metal discovered by Man. This view conforms to what was later noted by Coghlan.

1931. J Sebelien[8] expressed the belief that copper age could not exist in England because an alloy of copper and tin, ie tin bronze, could be supposedly made from the smelted copper ore. Sebelien thinks that local ores contained much tin. Thus, according to Sebelien, stone tools were immediately followed by bronze ones in England. But as H H Coghlan noted not all copper ores in the British Isles contained tin and this metal was not detected in chemical composition of the most ancient copper articles manufactured in the British Isles. J Sebelien also proposed that a copper age did not exist in Norway too because the stone tools were supposedly followed by iron ones there. He also doubted the existence of a copper age in Sweden and Denmark.

1935. J R Partington[10], an outstanding scholar of the history of chemistry, challenged the existence of copper age in the British Isles because the copper articles that had been believed to be made of pure copper supposedly contained over 10% of tin, ie he gave the same reasons as Sebelien.

In general, it can be surmised that the major part of considerations, unfavourable to the existence of copper age in some countries, that have been expressed, are based on the results of a limited number of laboratory analyses of ancient metal objects. Moreover, the validity of some of them obviously arouses doubts. At the same time the validity of age determination of supposedly most ancient articles with even more than 10% tin content in copper is also doubtful. In this case the occurrence of a great number of bronze objects in a monument in question represents bronze age, not the copper age, in accordance with the conventional principle to consider metal as determinant of historic epochs BC. Thus, it was necessary to find out whether the above-mentioned point of view representing the early stage of technological development in England was right. Coghlan's investigations proved the erroneousness of this assumption.

As the subsequent researches have shown the high value of arsenic content in copper happened to be more valid ground for doubts in a copper age existence than an independent stage in the history of mankind.

The study of chemical analyses data have shown that in a number of most ancient copper objects high arsenic contents were found though these articles had been considered to be made of pure copper. From the historical aspect it is not without interest to find when attention was paid to the arsenic content in copper articles and at the same time give information about each object of this kind. Here we give an account of some views from the sources available to us.

Rudolph Virhow[11] was one of the first researchers to note the excessive arsenic content in ancient objects. In his work published in 1891 he mentioned 3.41% arsenic content in a copper pin from Kumbolta (the Northern Caucasus). According to data supplied by A A Jessen[12] this article dates back to the end of the 2nd or the 1st millennium BC. There is no tin nor bismuth, sulphur or phosphorus in its chemical composition but there are traces of lead, zinc, iron, antimony and 96.61% of copper. Note that the chemical analyses of this object was carried out by analyst Rimbach. To all appearances R Virhow was the first to state that in the ancient Caucasus, as he put it, there existed 'a rare arsenical bronze' which differs from 'classic bronze' by its arsenic content side by side with a complete absence of tin in it. R Virhow was also the first to term an ancient alloy of copper and arsenic 'arsenical bronze', though this term seems to be purely conventional.

1899. Otto Helm[13] a scholar of the history of chemistry published a short report about the use of arsenical-copper alloys by ancient Egyptians. In the opinion of Helm it is explained by the fact that Egyptians knew their good physical properties because even small arsenic additions to copper makes it harder and gives a better product in the cast state.

1906. Marcelen Berthelot[4] having performed an analysis on some ancient Egyptian objects noted the presence of arsenic impurities in a few of them. For example, the arsenic content was detected in a fragment of copper vase found in the Dashur tomb, the latter dating back to the IV or the V Egyptian dynasty. Though the metal was completely oxidized the analysis determined 71.9% of copper and 4.3% of arsenic with non-metal impurities in its chemical composition. Berthelot explains that the presence of arsenic in ancient Egyptian copper results from the use of ore containing high arsenic impurities, ie he did not consider it the result of intentional addition.

1919. Edmund Lippmann[14] writes that tools and weapons in ancient Egypt were made of copper containing up to 4% of arsenic. He is of Berthelot's opinion that arsenic makes copper harder. He also mentioned that axes made of arsenical-copper alloys had been found in Charente and some other parts in France.

1924. A Gotzke[15] notes the supposedly frequent facts of arsenic detection in ancient bronze down to negligible parts of percent. He cited only two cases: an unspecified article from Serbia (Yugoslavia) and the copper pin from Kumbolta that had already been mentioned by R Virhow. A Gotzke seems not to realize which arsenical-copper objects should be mentioned as an example. Gotzke suggests intentional arsenic addition to copper despite the assumption that its presence in the chemical composition is the result of arsenic impurities in copper ore. He is not correct in claiming that the arsenic content decreased with the increase of tin content in ancient copper-tin alloys and arsenic ceased to be added with the appearance of 'real' tin bronze. The further investigations, ie the researches carried out after Gotzke's, have revealed that even when the tin bronze objects with high tin content appeared the arsenical-copper alloys had not disappeared at all, but they became rare.

Of interest too is that the arsenic content in ancient copper articles found in the Near East was noted by the special committee on Sumer under the British Association for the Advancement of Science. In 1933 Professor C H Desch[16] published 'An Interim Report' of the committee's activity. He mentioned the results of chemical analysis of some earlier ancient copper objects with arsenic content. Desch then asserted that arsenic as well as nickel are key elements whose presence in the chemical composition of articles could help to locate ore deposits, and the sources that provided Sumer with copper in ancient times. As it turned out later the frequent occurrence of arsenical copper objects in the Ancient World made location of ore deposits a far more difficult task.

1935. J R Partington[17], contributed to the study of copper age and arsenical-copper alloys of ancient origin. His work has not lost its significance for the science though the data is somewhat out-of-date. It is claimed that in Egypt, for example, the copper articles of somewhat later origin contained 1 or 2% of arsenic and, rarer, tin. Partington suggests neither the existence of arsenical-copper age or period ,nor the date of the coming tin bronze epoch. His assumptions and data about Egyptian arsenical-copper objects, and their production in ancient times are, nevertheless , valuable.

Having cited the facts that some very hard arsenical-copper axes, containing 2.8% of arsenic, were found in Charente (France) and the arsenic content in some samples of Egyptian ancient copper, Partington mentioned the current opinion about deliberate arsenic additions by using the arsenical mineral called arsenopyrite. But this mineral is claimed not to be found in Sinai.

Partington also gives the results of chemical analysis of a number of Egyptian copper articles with large amounts of arsenic in their chemical composition. Among them are the following: 1) An axe, aged 3500 years ago, containing 96.9% of copper, 1.5% of arsenic, 0.2% of tin, 0.7% of iron and traces of nickel sulphur and oxygen; 2) Six objects of unknown origin, one of them is 'multiarsenical' according to M Berthelot; 3) The above-mentioned fragment of a vase found by Jacque de Morgan on excavations in Dashur that contains 71.9% of copper and 'a considerable amount of arsenic' but tin, lead and zinc were absent. Note that the fragment was completely oxidized. It dated to the time of the IV or the V Egyptian dynasty, ie 2900-2475 ,when there was no tin content in copper alloys in Egypt; 4) A statuette of the Egyptian goddess Isis with her son Horus not quite definitely dated 'later than the VII century bc'. It contains 91.11% of copper, 1.72% of arsenic, 0.53% of iron, 0.08% of nickel together with cobalt, traces of lead and antimony, 0.26% of sulphur and no tin. It is the complete absence of tin and large amount of arsenic in the chemical composition of the statuette that favoured the opinion that arsenic seemed to be added in order to make a better product. Note that in the course of his investigations in the history of technology Partington did not carry out the chemical analysis of ancient metal objects, he just cited the data obtained by other chemists, basically the information supplied by M Berthelot and J Sebelien.

In 1936, arsenical-copper alloys of the ancient times were discussed in W Witter's works [18]. Note that he was one of the first researchers that paid particularly serious attention to the ancient arsenical-copper alloys, their advantage over pure copper, which, undoubtedly, were valued by ancient smelters. Witter states that pure copper characterized by poor casting properties could hardly be used for closed casting. Even a very small sulphur addition is sufficient for porous casting. Oxygen which is absorbed by copper acts in the same way. But even a small arsenic (or tin) content in copper is sufficient for getting solid castings. Thus, arsenic, as well as tin, acts as a deoxidizer, ie oxygen binding agent. Note that deoxidizing action is done by less than a 1% arsenic addition. Witter also mentions that in modern technology this effect is accomplished by phosphorus additions to copper, ie a small amount of phosphorus-copper is added.

He further attempted to stress the priority of Germany in the acquisition of knowledge about arsenical-copper alloys in the ancient times, He claimed that ancient German metallurgists learned to produce arsenical-copper alloys from arsenical sulphide ores, ie not by intentional additions. Thus, Witter assumes that the ancient metallurgists of Germany, by pure empirical choice of suitable copper ores, managed to smelt copper containing, for example, 4.18 and 4.21% of arsenic. The arsenic content was determined by spectral analysis of ancient copper daggers made in Germany.

W Witter acknowledges that arsenical-copper articles existed in Egypt for the past 4000 years, in Cyprus, and later in South America. In Egypt, for instance, an axe (dated back to 2000 BC) containing 93.23% of copper, 3.90% of arsenic, only 0.52% of tin, 0.15% of antimony, and 0.21% of iron, was found.

Note Witter's assertion challenging the assumption that arsenic was deliberately added to copper in order to make it harder. He does not believe the level of technological knowledge to be sufficient in terms of necessity to add arsenic to copper. In his opinion only the copper production from arsenical copper ores, ie ores rich in associated arsenic, can be discussed. Thus smelted arsenical copper, because of its better qualities, was favoured over other kinds of copper. He also amends the statement, made by a number of scholars, that arsenic addition in melted copper makes the resulting alloy harder. But in reality, as Witter puts it, arsenic content in arsenical copper does not make the metal harder; the hardness increases only if the alloy has been subjected to cold forging. It is after cold forging that they become harder. Witter cites the data obtained by other researchers. It is claimed that arsenical-copper alloys containing 7.25% of arsenic can be subjected to cold forging without cracking while the alloys, containing upwards of 1.94% of arsenic, are easily rolled. Witter stresses that experience which the ancient smelters acquired for many centuries had taught them which deposits provided ore for casting better metal, ie arsenical copper. As for the age of arsenical-copper daggers from Germany Witter only supposes that they were made 'in the last stage of period I according to Montelius'.

1949. E R Caley [19] , having published the results of chemical analysis of arsenical-copper articles from the Aegean area, draws attention to the frequent occurrence of the ancient objects of the same chemical composition in Central Europe as well as Mesopotamia. He also stresses that the use of arsenical-copper alloys in ancient times is of interest for the study of the discovery and later use of tin bronze. E R Caley simultaneously revealed a certain parallelism by comparing the arsenical-copper objects from other regions. But these objects cannot prove the existence of a special historic period in any of these regions because tin copper objects were used side by side with arsenical-copper ones, for example, the articles from the site of ancient town of Termi. E R Caley does not think it necessary to come to any conclusions unless the results of analysis of quite reliably dated arsenical copper articles of ancient origin are available.

1951. T Burton-Brown [20] excavated an ancient settlement on the hill Geoy-Tepe near Lake Urmia in Southern Azerbaijan in 1948 . The metal objects were found in the lowest stratum dated back to about 3200 BC. Two of them are shapeless, they appeared to be two small spillings and the edge of a knife. This find was not subjected to spectral-analysis. Unfortunately, it is rather difficult to estimate the composition of the two above-mentioned objects for they were completely oxidized. The spectral analysis of these objects and the other articles found on excavation of this settlement was only a semi-quantitative one. The analyses have shown that both samples are made of copper. Their chemical composition also include 0.005 and 0.001% of tin, 0.01% of lead; 0.02-0-005% of arsenic; 0.1 and 0.01% of antimony; 0.1 and 0.01% of silver; 0.0005 and 0.002% of bismuth; 0.01 and 0.03% of nickel; some hundredths of percent of iron and phosphorus.

Several copper articles were found in an upper stratum dated back to the beginning of the 3rd millennium BC. Two of them supposedly contained 1.0% of arsenic, three – 0.2%, one – 0.1%. Thus Burton-Brown determined the appearance of arsenical-copper objects in Geoy-Tepe at the beginning of the 3rd millenium BC. Note that these objects also were in a very bad condition and the validity of the results of their semi-quantitative analyses, carried out under the guidance of Dr E Voce, caused some doubts. According to explanations of Dr Voce, cited in T Burton-Brown's work ,the spectral analysis gave 'approximate quantitative' data about the additions to copper and its alloys. This statement proves the necessity of quantitative spectral analysis. Certainly, one can only assume the existence of an arsenical-copper period in Iran too.

1954 . O E Lippmann[21] accepted the idea of the existence of a copper age in a number of countries before the coming of the bronze age. But he mentions that arsenical-copper objects were also used during this period in the history of mankind. In his opinion, arsenical-copper objects should be considered as copper ones, which is a gross mistake. This assumption contradicts H H Coghlan's and I R Selimkhanov's conclusions*. But Lippmann stresses that arsenical-copper tools were used side by side with copper articles in a major part of the countries in the Old World and even the New World from the very beginning of the copper age. Among those countries he mentioned Central Germany and Peru, besides Egypt and Cyprus. The arsenic content in copper is claimed to amount to 4% in these regions. It goes without saying that Lippmann's statement about the maximum . arsenic content in copper and the existence of a copper age in all countries in 2000 BC should be considered out-of-date.

The Researches Carried Out in the Laboratory in Baku

1958 . I R Selimkhanov[22] was the first to state the hypothetical character of copper age existence on the territory of Azerbaijan SSR. The theory of arsenical-copper age or period in the history of ancient metal and metallurgy in Azerbaijan was put forward. A little about these investigations.

Enormous factual material had been gathered as a result of numerous archaeological excavations carried out on the territory of Azerbaijan SSR. It was indicative of the development of ancient material culture of the Azerbaijan people. A considerable number of finds were metal articles made of copper or its alloys.

In 1952 a number of questions concerning the chemical composition of ancient bronze alloys and the characteristic features of metals used as alloying elements in ancient times were raised. These were raised in view of the necessity of clearing up some points concerning the history of technology and to determine the origin of tin in ancient tin bronze of Azerbaijan. Simultaneously, a number of other problems connected with the history of metal and the development of metallurgy in ancient Azerbaijan had to be solved. The investigations were based on a solid scientific foundation when chemical analysis and, later, quantitative spectral analysis became to be used.

The researchers in the laboratory first of all faced the problem of the most effective methods of quantitative analysis. The techniques of wet chemical analysis of ancient copper and bronze objects described in the literature are not very good for they require large samples, whose taking can cause damage or even elimination of the object. Moreover, the use of these techniques makes the investigation very painstaking and lengthy.

In the laboratory of Baku it was decided to employ the spectral method of analysis. This method serves to determine even small amounts of metallic impurities (down to 10^{-3} 10^{-5} % sometimes even less) in an investigated object. As for the quantitative determination of characteristic impurities in copper alloys, only very small samples, usually not more than 10-30 mg, are needed. It is also known that spectral analysis is objective and its results are stated on the photoplate by spectral lines of various intensity and extent of blackening. They can be always tested if necessary. This advantage of spectral analysis in comparison with the usual methods of the investigation of chemical composition of alloys makes this technique indispensable in the study of ancient metals.

Note that the qualitative spectral analysis in the study of ancient copper and bronze objects began to be used as early as 1933-1935 in Leningrad. Almost at the same time the technique of quantitative spectral analysis of ancient metal articles was developed and put into use in Halle (GDR). But a certain complexity of sampling and standard making for analysis made the laboratory of Baku find its own method of quantitative spectral analysis.

As a result of the investigations carried out in our laboratory the method of spectral analysis by means of evaporation of the alloy, which has already been converted into the oxide state, under spectrum excitation in activated alternating current arc (the current is 15A, the voltage 220 V) was developed. The samples of copper alloy weighing 0.2-0.3 gr were put in an evaporating dish made of pyrex glass or quartz and dissolved in diluted nitric acid. This solution with the precipitate of insoluble matter was evaporated away and the thus-formed metallic nitrates were converted into the oxides.

The standards were prepared by dissolving measured quantities of copper with the metallic impurities to be determined of the alloy in question, which have been converted into oxides in the same way. As experience has shown ,the copper oxides when put in the carbon electrode crater are reduced to molten metal, which begins to spray in the alternating current arc. For this reason metallic oxides samples used to be mixed with carbo-barium mixture (80% of pure carbon powder + 20% of barium nitrate) and fixed in the carbon electrode crater by impregnation with alcohol polyvinylbutiral solution. Magnified arc images were projected on the slit of spectrograph ISP-22 through three-lens optical system with interval diaphragm.

The photographing of spectra was done through a nine-step platinum attenuator. It provided the researchers with ample opportunity to use one and the same spectrogramme for qualitative, semi-quantitative and quantitative analyses. The described method was used to investigate copper and bronze objects, remainders of casting, moulds and slag from Eneolithic monuments in Azerbaijan, Kul-Tepe, the settlement near the town of Nakhichevan, and the kurgans in the town of Stepanakert. These monuments dated back to the 3rd and 3rd-2nd millenia BC had been considered to belong to the copper age. The investigation conducted in the laboratory of Baku showed that all metal objects were made of arsenical-copper alloys (1.66%-6-12% arsenical addition) side by side with the absence of tin in their chemical composition.

Local arsenic ores, realgar-auripigment from the Julfa deposit, were also subjected to spectral analysis in order to determine the sources of ores used for arsenical-copper alloys production. One can come to the conclusion that these ores were used by ancient smelters to produce arsenical-copper alloys if we take into consideration the chemical composition and the geographical situation of the above-mentioned ores. Copper ore could be taken from the neighbouring Kul-Tepe Kafan deposit situated in the territory of Armenia SSR.

Arsenical-copper articles occur in 'Eneolithic' monuments side by side with the complete absence of pure copper objects among articles, having found by that time, gave a good reason to believe that the 'copper age' should be considered hypothetical for this territory. The earliest stage of metal was that of 'arsenical-copper' when the population

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* Note: See below the publications of H H Coghlan and I R Selimkhanov.

had already learnt to obtain arsenical-copper alloys by joint smelting of ores but the properties of tin as copper alloying element had not yet been discovered.

A little later O A Abibullaer[23] obtained 7 metal objects in the low stratum of Kul-Tepe hill having reached the subsoil. Strictly speaking, they were found in the upper half of the low stratum and can be dated to the time span from the beginning to the middle of the 4th millennium BC. All of them happened to be greatly oxidized; that is why the samples analysed at the laboratory of Baku could be taken either from oxidized metal or from 'green patina'. Two beads found there were a conglomeration of corrosion products of former metal.

Three objects contained considerable arsenic impurities, for example, there were 1.4% of arsenic, 0.15% of lead and small amount of other metals in the chemical composition of an arrow-head. It was determined that a fragment of an unidentified object contained 0.41% of arsenic, the other metals impurities varied from thousandths to hundredths parts of a percent. The 3rd object, a kind of piercer, was found two meters higher. Its metal was classified as 'copper-arsenic-nickel '.The chemical composition of this article consists of 1.15% of arsenic, 1.6% of nickel, 0.2% of antimony and other metals (tin, silver, bismuth, cobalt, iron) from thousandths to hundredths parts of a percent.

The additional data obtained by quantitative spectral analysis gave a good reason to believe that there was no 'pure copper age' in the territory of the Azerbaijan SSR, for small non-arsenical copper articles-ornaments – were used side by side with objects made of arsenical-copper alloys. That is why it is better to consider the arsenical-copper age or period as the most ancient technological stage of this region. Later, within the limits of our objective to determine the geographical boundaries of arsenic-copper age or the period of its extention, the most ancient metal objects from Armenia, dated to the same time-span as the articles from Kul-Tepe, were subjected to spectral analysis at the laboratory of Baku. They are the metal objects from the settlement of Tekhuta dated back to the beginning of the 4th millenium BC by the excavator, R M Torosyan[24] Two fragments of awls and a small knife were found at the base of one adobe hut in this settlement side by side with many tools made of flint, obsidian, basalt and bone. According to spectral analysis a knife weighing 5.5 gr, as well as one fragment of an awl weighing 0.8 gr happened to be arsenical-copper with 5.4% and 3.6% of arsenic in their chemical composition. Note that the knife was in bad condition. The other impurities were inconsiderable, they vary from thousandths to tenths of a percent. Of interest is a somewhat large amount of silver (0.18%) and nickel (0.1%) in the fragment of the awl.

According to all available data metal articles of the 4th millennium BC have not been found in Georgia and in the Northern Caucasus.

Metal Articles of the 3rd Millennium BC.

Besides Azerbaijan, metal objects of the 3rd millennium BC were found in Armenia, Georgia, and in the number of monuments in the Northern Caucasus. Metal objects of the 3rd and 2nd millennia BC, besides the settlement of Kul-Tepe in the 3rd millennium BC and the 3rd and the 2nd millennia in the town of Stepanakert, were also found in other regions of the Azerbaijan SSR. All these metal articles were analysed in the laboratory at Baku and happened to be made of arsenical-copper alloys with various arsenic contents. In Fisuli region, 10 objects were found in Garakepecktepe, the monument belonging to the time-span of 3000 years BC. They are: 3 spear-heads containing 0.95, 1.45 and 1.51% of arsenic with complete absence of tin, antimony, zinc, bismuth, cobalt; 2 rings containing 0.62 and 2.8% of arsenic with absence of the above mentioned metals; 2 pins containing 0.31 and 1.04% of arsenic; a fragment of bracelet containing 0.32% of arsenic with the absence of the same metals; 2 fragments of unidentified objects containing 0.23 and 6.53% of arsenic.

In the settlement of Misharchai dated to the 3rd millennium BC in the vicinity of the town of Astrakhanbazar various objects were found containing from 1.33% to 3.75% of arsenic while one adze-shaped object contains 1.1% of nickel, ie it is a copper-arsenic-nickel alloy.

Three arsenical-copper objects were found on excavation of a burial mound near a reservoir in Khachbulagh. One of them was a spear-head containing 2.8% of arsenic and another one, an awl containing 3.2% of arsenic. This information about the chemical composition of ancient copper objects that happened to be arsenical-copper proved the existence of arsenical-copper age or period as the first technological stage of the use of metal in Azerbaijan. This stage began in the 4th millennium BC and continued at least until the end of the 3rd millennium BC. As a rule, there is no tin in the composition of arsenical-copper alloys or the amount of tin is expressed in fractions of a percent which seems to depend upon the chemical composition of copper ores with which it was associated.

Thus, the spectral analysis researches conducted in the laboratory of Baku have shown that the metal articles dated back to the 3rd and the end of the 3rd millennium BC found on excavation of monuments in Armenia, Georgia, Dagoestan, Stavropol territory, the Kuban-river basin and the Ukraine are in the majority of cases made of arsenical-copper. Among them copper-arsenic-nickel articles can be found but tin-copper ones do not occur. It follows that the boundaries of arsenical copper age or period lie beyond the limits of Azerbaijan and include an extensive area in the Northern Caucasus and Iran. According to the current researches carried out in Iran the beginning of the use of arsenical-copper objects in Iran dates back to the 4th millennium BC and tin appeared in the chemical composition of Iranian copper only at the beginning of the 3rd millennium BC*. (See below).

It seems that corroboration of the arsenical-copper age in a number of other countries has been presented following the researches carried out in the laboratory of Baku.

V A Pazukhin on Arsenical-Copper Alloys and their Origin

In 1964 V A Pazukhin[25] carried out some very interesting researches in order to determine the origin of ancient arsenical-copper alloys. It was claimed that arsenical-copper objects prevail among the earliest copper articles in many countries, for example, in the Caucasus, Ireland, Britain, partially in Southern Spain and even China. In his opinion, a wide-spread assumption that arsenical-copper articles were made of native arsenical-copper found,for example, in Iran and in the region of the Lake Superior, is not true. He also challenges the use of oxidized copper ores with some arsenic content. He asserts that they both are incomparably rarer than expected, ie without arsenic. Pazukhin also contradicts the statement that the ancient smelters used to choose such copper ores that contained arsenic in order to get copper with greater or lesser arsenic content in the chemical composition by their smelting. Further, the smelting of ancient arsenical-copper out of tetrahedrite only, which should be roasted first is considered hardly probable. Moreover, Fahlerz ores are dark and tarnished. They do not occur at the exposures and do not attract attention as oxidized copper ores do.

At the same time, V A Pazukhin thinks that ancient smelters knew a reliable and simple way of obtaining arsenical-copper alloys either by joint smelting of oxidized copper ores with arsenical minerals or by their addition to already smelted copper. He also determined that the likeliest additives would be conspicuous minerals: golden auripigment or scarlet realgar, while uncomely dark tennantite and native arsenic, which is very rare and soon gets tarnished, are less likely. Pazukhin does not reject the possibility that ancient smelters used silvery arsenopyrite or lelengite for this purpose. Beads are known to be made of these minerals in ancient times.

These considerations caused V A Pazukhin to carry out a series of test smeltings with arsenical mineral additions under a carbon layer with electrolytic copper powder and,further, with its oxide and pure malachite.

These test smeltings carried out under the guidance of V A Pazukhin proved the possibility of obtaining the arsenical-copper alloys by the introduction of arsenical mineral sulphides to oxidized copper minerals.

Of interest also are the results of the analysis of mechanical properties of the thus obtained arsenical-copper alloys. To test the mechanical properties of the alloys they were melted in graphite crucibles with a mould. It is noted that wonderful casting properties of arsenical-copper were evident. Test specimens were turned out of billets. It was determined that the billets were not so ductile as copper; for an alloy with 7.5% arsenic content the percentage elongation was only 7%, though it is capable of being forged.

A few remarks should be made concerning this undoubtedly valuable work of V A Pazukhin. He could not obtain alloys containing more than 7.5% of arsenic by the test smelting. Note that these alloys often occur among arsenical coppers and the fact that even greater amounts of arsenic are found in the chemical composition of ornaments made of arsenical-copper was not taken into account. Further, as it is known from the investigations conducted not only in the laboratory at Baku, arsenical-copper alloy production was gradually vanishing with the appearance of the bronze because of toxicity of arsenic compounds. In the course of the smelting of copper and arsenical minerals not only the smelters, but all living things around died. V A Pazukhin's tests are claimed to show that arsenical alloy smelting is not dangerous, for gaseous sulphur dioxide which is given off in the process of smelting, would have forced foundry-men to keep to the side of the hearth exposed to the wind. Note that not only sulphur dioxide is given off during this kind of smelting but the arsenic compounds which have a toxic effect. In this case the idea of avoiding the danger by careful choice of smelters' position seems somewhat naive. In our opinion, the further test smelting of arsenical-copper alloys containing a large percentage of arsenic should be carried out.

In the same year PR Moorey[27] investigated a number of ancient Iranian metal articles referred to as 'Luristanian'. These articles are kept in the Ashmolean Museum in Oxford. Moorey distinguished two objects, an axe, and a dagger, found to be the earliest. He considers them to be similar to Elamite and Sumerian types which are dated back to the middle of the 3rd millennium BC. The dagger, according to the information he possessed, is a prototype of a gold dagger from the Royal Graves at Ur. The analysis of both objects showed that they were made of arsenical copper with 4.5% and 3.7% arsenic in the dagger and the axe respectively.

In the conclusion to this research Moorey mentions that there existed a technological stage of the use of arsenical-copper alloys in some areas of South-West Asia. He also determined the time of this period's existence. For example it existed in Southern Mesopotamia from the end of the IV Millennium BC, and later in Assyria and North West Iran.

But nowadays these chronological data should be considered out-of-date, especially for the Caucasus. As for Iran, it was somewhat later than R F Tylecote and H McKerrell[28] noted the earlier existence of arsenical-copper metallurgy in Iran. Their assertion was based on the results of the analyses of metal objects from the settlement of Tal-i-Yahya, situated 200 km to the South of the town of Kerman. Two of them, dated back to about 3800 BC, happened to be made of arsenical-copper alloys. One of them, a chisel, contained 3.7% of arsenic, an awl only 0.3%. H H Coghlan mentioned that in the course of treatment the metal could have lost a part of arsenic content but the arsenic content was greater in the original metal. Both articles were made of smelted copper cast into moulds and subjected to repeated successive heating and forging.

Thus the period of the appearance of arsenical-copper in Iran was synchronous with arsenical-copper objects in the Azerbaijan and Armenia (USSR).

H H Coghlan's Researches

In 1957, H H Coghlan and H Case[29] published some ideas connected with the smelting of arsenical-copper and antimony copper alloys in ancient times. It was originally explained by the use of Fahlerz ores containing much arsenic and antimony. A part of the arsenic and antimony is believed to remain in smelted copper. In their opinion, the ancient smelters obtained arsenical-copper alloys with approximately similar arsenic content either by the choice of ores or by controlling the smelting process. The last assumption as mentioned above, is challenged by V A Pazukhin. But Coghlan rejected the idea of deliberate introduction of metallic arsenic to copper.

1969. H H Coghlan and G Parker[30] with a reference to R F Tylecote[31] mentioned that during the copper age arsenical-copper objects had been used side by side with copper articles in the British Isles. These objects were dated to about 1850-1650 BC, then the early bronze age followed. In connection with Tylecote's assertion Coghlan stresses that there are plenty of examples of arsenical-copper objects but the use of pure copper is not so easily proved. Thus, Coghlan reported that there were only 11 objects made of pure copper, ie without arsenic content, which could be assigned to the copper age in contrast to an arsenical copper age or period. That is why he gives so much attention to the results of analysis of two axes. According to the analyses these axes were made of pure copper and, therefore, they represent additional proof of great archaeological importance.

Thus Coghlan, with Parker, still held the opinion that the existence of a copper age preceding the arsenical-copper age was characteristic for the British Isles with Ireland in certain archaeological periods.

1975. H H Coghlan was introducing important corrections to his former statement, noting that 'when the process of smelting was discovered, the oxide, carbonate and other ores of copper were exploited and these ores would have given both pure and impure coppers' Coghlan stressed that 'not so long after the discovery of smelting, objects made of arsenical-copper began to appear'. He also states that 'in fact owing to the marked prevalence of arsenical-copper in some countries it would perhaps be more correct to speak of an arsenical copper age or period, rather than the more general term of copper age' Further he writes that the use of arsenical-copper was extensive and widespread both in Europe and in the East. In his opinion, this follows from reference to long series of analyses carried out by the Stuttgart Group [33] by Selimkhanov [34] and by Selimhhanov and Maréchal in France [35]

Conclusion

We have briefly examined the problem of an arsenical-copper age or period. Because of the limited size of the present work it does not fully cover the subject. The results of investigations carried out by some prominent scholars, whose conclusions concern the present problem, have not been discussed. One of them is the valuable work of H Otto – W Witter [36]. We have given an account of opinions and assumptions about the existence of copper age and arsenical-copper age in some areas. The researches carried out at the laboratory of archaeological technology in Baku have been mentioned. As a result of these investigations we suggested the hypothetical character of a copper age and the existence of an arsenical-copper age or period, first in Azerbaijan, and later in the Caucasus as a whole. This conclusion, drawn as far back as 1958-1960, was corroborated by a prominent scholar of the history of the ancient metallurgy, H H Coghlan. In fact, he supported the theory of the existence of arsenical-copper age or period in certain countries of Europe and Asia.

The tragic news of the death of H H Coghlan in 1981 causes us deep sorrow. The disappearance of a great scientist and good friend closes more than 20 years of fruitful, amicable co-operation.

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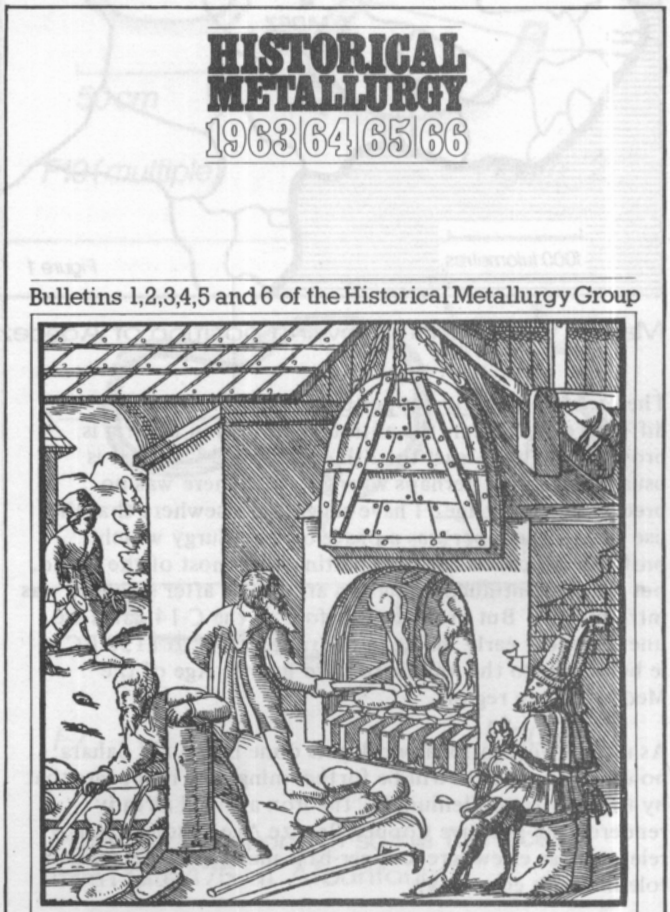
Historical Metallurgy in retrospect

Concurrent with the publication of this issue of *Historical Metallurgy*, a new volume incorporating the material previously issued as *Bulletins 1 to 6* of the Historical Metallurgy Group, together with several new drawings and photographs of early furnaces etc is being published by the Society.

It contains the earliest known systematic lists of early British blast furnaces, articles on the management and technical operation of 17th century ironworks and regular progress reports on the series of excavations and investigations which provided the broad base upon which the Historical Metallurgy Society was developed.

This new publication is produced in the same format and typographic style as current *Journals* and together with *Bulletins 7 to 9* and subsequent Volumes from 2 onwards (1968 to date) constitute a comprehensive record of organised historical metallurgical activity for the last twenty years.

Copies of *Historical Metallurgy 1963/66* can be obtained from Roger Wood 99 High Lane West, West Hallam, Derbyshire DE7 6HQ at £3.95 plus postage and packing. Back numbers of some of the early *Bulletins/Journals* are also obtainable.



HISTORICAL METALLURGY 1963|64|65|66

Bulletins 1,2,3,4,5 and 6 of the Historical Metallurgy Group

Early copper slags and copper-base metal from the Agadez region of Niger

R F Tylecote

Introduction

Many of H H Coghlan's early papers were on the working of native copper and the smelting of pure copper minerals under very primitive conditions[1,2]. In this paper we appear to be dealing with the problem of identifying one or other of these processes.

The South-West Sahara is a heavily mineralised area and attention is now being paid to the iron and copper resources of Mauritania and Mali, and the uranium resources of Niger (see map in Fig 1). It is not surprising therefore to find that early man had already located and used some of these deposits, especially the copper and iron.

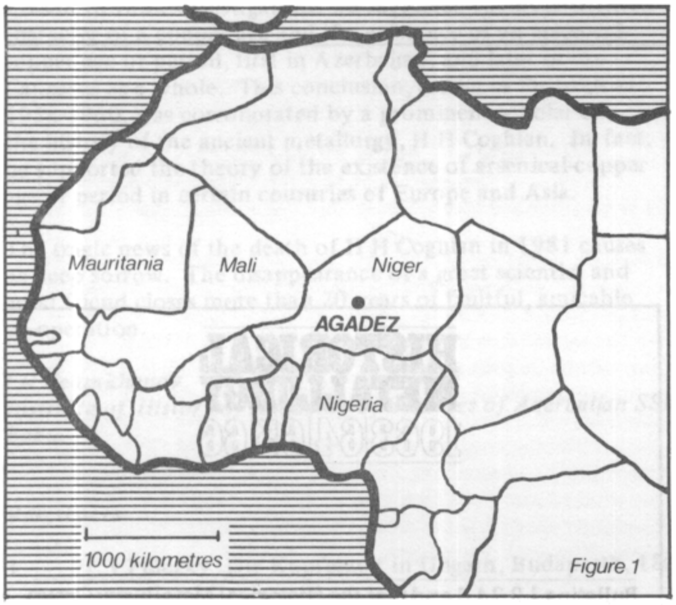


Figure 1

Map of West Africa showing position of Agadez

The problem of early copper cultures in W Africa is a difficult one. So far, the antiquity of iron in Nigeria is proved back to at least the 4th century BC[3]. But it is usually accepted, perhaps wrongly, that there was no preceding copper age. I have suggested elsewhere that the use of native copper was a phase of metallurgy which probably preceded copper smelting over most of the world, but that it continued in certain areas long after smelting was introduced[4]. But in the case before us the C-14 dates are unexpectedly early, being in the range 2190 to 1150 BC, ie belonging to the Middle to Late Bronze Age of the Mediterranean region.

As more investigational work gets done in the SW Sahara, no doubt more data will be forthcoming, but it appears that by the mid 1st millenium BC the iron age had already rendered the putative Copper/Bronze Age obsolete and relegated, as elsewhere, copper-base metals to a decorative role in man's economy.

As a result of field work by a French team in Niger a number of slags and pieces of copper-base metal were submitted for analysis. Detailed reports on the finding of this material have already appeared [5,6].

Geology and Mineralogy

The region has copper mineralisation in the form of copper-containing dolomites[6]. This material contains 'grains' of native copper several mm in diameter disseminated near the periphery of blocks of dolomite 10cm or less in size. The stratification of this mineralised dolomite is roughly horizontal and in places it is exposed on the desert floor. After working, noticeable depressions are left.

In some areas the native copper seems to have been completely oxidised to cuprite, malachite, tenorite etc and it would appear that many of the native copper grains had cuprite envelopes. The copper content is estimated as 2.36% in a typical piece of cupriferous dolomite[6].

The only crystalline phase identified by XRD was chrysocolla ($CuSiO_3$). Cuprite, tenorite and malachite was sought but not found. A thick-section micrograph shows a lot of green phase and some well-rounded grains of silica with a hardness of 1300 HV. The unidentified green matrix was soft with a hardness of 102 HV. In one area there was a good deal of fine metallic copper with a hardness of 100-180 HV.

Clearly, this is a native copper which seems to have oxidised and partly dissolved in the course of time, trapping silica sand and forming a green oxidised matrix, one component of which is chrysocolla.

Many of the stones in the working areas contain hollows for grinding, and hammer stones can readily be found[6]. It is claimed that conical crucibles did exist but the sherds seem small and their attribution doubtful[6].

The Furnaces

The copper working furnaces consisted of hard-burnt clay-sand fired to red and black colours but they were not slagged like copper smelting furnaces found in Timna, Israel and in Iran. Some plans and sections of the furnace cavities from Site 175 at Afounfoun are shown in Figs 2 and 3. These show the simpler types; others are more complicated and it is difficult to explain how they were used. But those shown bear a marked resemblance to some well-known European smithing furnaces and there would be no difficulty in accepting them as furnaces for the melting of copper-base metals in crucibles. All, however, were free of adherent slag and it seems that the hardening was due to heating with charcoal by the aid of bellows. The temperatures reached probably exceeded 1000°C on the lining which would be consistent with melting metals at 1100°C. The bases of some of the later furnaces were cylindrical; others had a re-entrant form strongly resembling some West African iron smelting furnaces dated to the 4th-2nd century BC[3].

Charcoal samples were taken from the bottom of the copper working furnaces. The results from three sites near Agadez from which the slags were analysed are given in

Table 1. These cover the range 2190 BC to 670 AD and fall into three groups: – Copper I, Copper II and Iron Age[7].

Table 1

Carbon – 14 dates for Agadez sites (not calibrated)
(After Grébenart et al[7])

Copper Age 1

Afounfoun Site 175

Furnace 1	1970 + 90 bc (GIF) 2190 + 90 bc
Furnace 2	1650 + 90 bc 1850 + 90 bc
Furnace 3	1730 + 50 bc
Furnace 4	1150 + 70 bc
Furnace 5	1630 + 100 bc
Furnace 7	1730 + 100 bc
Furnace 8	1710 + 110 bc
Furnace 12	1560 + 100 bc

Copper Age II

Afounfoun Site 162

Furnace 9	570 + 90 bc (GIF)
Furnace 10	570 + 90 bc
Furnace 25	850 + 90 bc
Furnace 28	590 + 90 bc
Furnace 44	790 + 90 bc

Ikawaten Site 193

Furnace 1	670 + 70 ad (GIF)
Furnace 3	140 + 90 bc
Furnace 7	210 + 90 bc

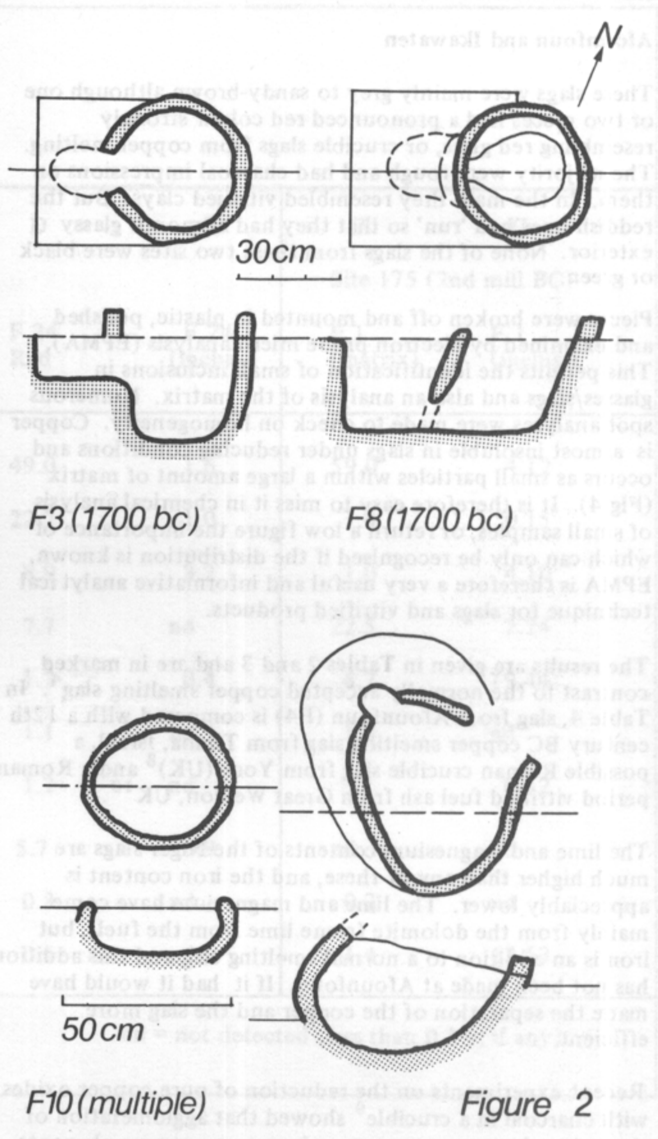


Figure 2

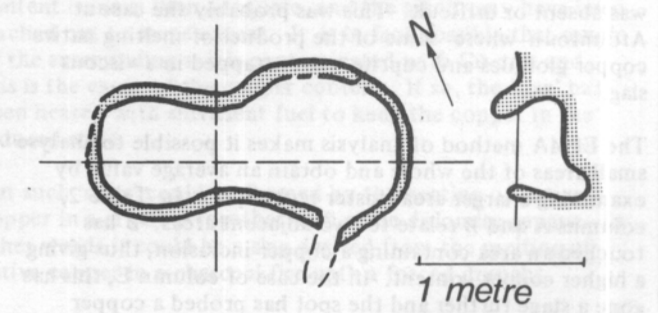


Figure 3

Plans and sections of some furnaces from Site 175 at Afounfoun

Slag Analysis

Afounfoun and Ikawaten

These slags were mainly grey to sandy-brown although one or two pieces had a pronounced red colour strongly resembling red glass, or crucible slags from copper melting. The majority were rough and had charcoal impressions on them. In the main they resembled vitrified clays. But the reddish ones had 'run' so that they had a smooth glassy exterior. None of the slags from these two sites were black or green.

Pieces were broken off and mounted in plastic, polished and examined by electron probe micro analysis (EPMA). This permits the identification of small inclusions in glasses/slags and also an analysis of the matrix. Numerous spot analyses were made to check on homogeneity. Copper is almost insoluble in slags under reducing conditions and occurs as small particles within a large amount of matrix (Fig 4). It is therefore easy to miss it in chemical analysis of small samples, or return a low figure the importance of which can only be recognised if the distribution is known. EPMA is therefore a very useful and informative analytical technique for slags and vitrified products.

The results are given in Tables 2 and 3 and are in marked contrast to the normally accepted copper smelting slag[4]. In Table 4, slag from Afounfoun (F4) is compared with a 12th century BC copper smelting slag from Timna, Israel, a possible Roman crucible slag from York (UK)[8] and a Roman period vitrified fuel ash from Great Weldon, UK[10].

The lime and magnesium contents of the Niger slags are much higher than any of these, and the iron content is appreciably lower. The lime and magnesium have come mainly from the dolomite (some lime from the fuel), but iron is an addition to a normal smelting slag and this addition has not been made at Afounfoun. If it had it would have made the separation of the copper and the slag more efficient.

Recent experiments on the reduction of pure copper oxides with charcoal in a crucible[9] showed that agglomeration of the reduced copper was easy as long as no gangue elements were present. But when slag was present agglomeration was absent or difficult. This was probably the case at Afounfoun where some of the product of melting native copper globules and cuprite was entrapped in a viscous slag.

The EPMA method of analysis makes it possible to analyse small areas of the whole and obtain an average value by examining a larger area (raster technique). In Table 2, columns A and B relate to two adjacent areas; B has touched an area containing a copper inclusion, thus giving a higher copper content. In the case of column E, this has gone a stage further and the spot has probed a copper inclusion almost entirely. It is clear that these do not contain much iron, unlike the Timna 2 slag[4] (Table 4) where the copper content of the iron was high. On the other hand the inclusion had a high magnesium content which is confirmed by the copper inclusion (SP1) in the Ikawaten slag (Table 3). These inclusions apparently contain unslagged particles of MgO from the dolomite. It was also noticed that slag 175 (Col G, Table 1) contained inclusions of titanium-iron compounds, perhaps of rutile and ilmenite.

In most cases the CaO/MgO ratio is about 3/1 which possibly reflects the composition of the dolomite, with additions of CaO from the fuel ash. On the whole the fuel ash was higher in sodium than potassium and the totals of the two oxides can be as high as 7.00% (Table 3, SP2). Considering that some of this must have been leached in the course of time, the original value probably exceeded 10%.

The slag from sites 112, 157 and 169 was quite different. It was heavy and black and clearly an iron working slag, either from smelting or forging.

Analysis of Metal

This was in the form of metal droplets from the hearths and purposeful artifacts. These were all non-magnetic and therefore do not contain more than 1% iron.

Two droplets were examined. (A) etched rapidly in ferric chloride and was clearly a copper-base solid solution. It contained some spherical inclusions of slag together with some irregular particles. The hardness was 95 HV 0.5. The second, (B), was very similar to the first with a small amount of a second phase which was situated intergranularly. It is not cored and so must have been heated after solidification probably by falling into the fire. The hardness is 83 HV 0.5. Both of these are impure copper and the main impurity is arsenic at about 0.5%.

Two artifacts were also examined. A piece was cut from a small chisel-like object and this etched rapidly in ferric choride to reveal a copper-base solid solution containing much slag. There was some residual coring showing its original cast origin but this has been mostly removed by subsequent heating and working which has resulted in a fine-grained and twinned structure. The hardness is 164 HV 0.5 which shows that it has been hardened by cold working. This piece looks remarkably like some early arsenical copper from Cyprus, and XRF confirmed that arsenic was present in the range 2.5 to 3.0%.

The second piece was cut from a small thin blade. It etched even more rapidly than the above but is very similar in many ways. The structure is coarser but equiaxed and twinned. No deformation markings nor bent twins are visible and this and the hardness of 83 HV suggest that not much cold work, if any, was done on it.

Discussion

The majority of the furnaces from the Copper Age I (2000-1000 BC) are holes in the ground lined with sandy clay which has not been vitrified during use nor combined with a cupriferous slag. They have a marked resemblance to European smithing furnaces used both for iron and copper working. A tuyere would be necessary but these might not have been so well burnt as the lining and would be more likely to have been weathered away. But some furnaces seem to have integral tuyeres.

The slags contain copper but are quite unlike European copper smelting slags or even some crucible slags which normally contain appreciable iron (Table 4). Minor element analyses by J R Bourhis[11] are given in Table 5 and agree with our analyses. Unfortunately they do not give Ca and Mg. The fact that magnesium seems to be present at or in the metal is of considerable interest. It has been reported for tin bronzes found in Sinai[12]. While it is possible for magnesium to alloy with copper (both as a solid solution and as a compound[13]), it is more likely to be present as a dolomitic inclusion.

Many of the copper artifacts found on Sites 162, 175 at Afounfoun, and Site 193 as Ikawaten have been analysed[7]

Table 2

Slag Analyses – Afounfoun

%	A	B	C	D	E	F	G
	Site 162, (c. 800 BC)					Site 175 (2nd mill BC)	
	F 10 (1)	F 10 (2) (inclus.)	F 14	F 24 Red	F 24 (inclus.)	F 1 (matrix)	F 1 (inclus.)
SiO_2	44.4	42.4	43.0	49.0	1.6	59.0	4.12
CaO	29.6	28.5	27.0	22.7	1.0	1.4	0.15
MgO	10.8	10.2	10.0	8.9	3.2	1.0	4.10
Al_2O_3	7.1	7.0	7.9	7.7	nd	22.5	7.24
FeO	1.5	1.5	2.1	1.2	0.4	6.7	19.44
Na_2O	2.99	1.2	2.6	1.1	nd	1.3	nd
K_2O	1.1	1.0	0.9	1.2	nd	3.1	0.32
Cu *	0.34	5.9	1.2	5.7	93.9	nd	nd
MnO	0.38	0.4	nd	0.3	nd	0.2	nd
TiO_2	0.53	0.6	nd	0.6	nd	1.4	62.53

* Metallic copper, not oxide.

nd = not detected (less than 0.1%, if any).

(Table 6). The raw copper is relatively pure except for iron and arsenic, but some bronzes were found and it would appear that bronze was being melted and possibly alloyed. But the zinc-containing bracelet from Afounfoun 162 was probably a late intrusion.

The iron and arsenic contents are very typical of early copper smelted from oxide ores using iron fluxes. Some of the raw material contains As but not iron and is more like what one would expect from the local minerals. The high iron contents may have come from iron minerals in the dolomite that were accidentally reduced or may represent a totally different source smelted with an iron-bearing flux. It is unlikely that they can be associated with a slag containing only 0.5 - 7.0% FeO. Iron contents exceeding 1% in the copper metal render it ferro-magnetic.

Conclusions

The slags from Afounfoun and Ikawaten are not copper smelting slags because their FeO contents are not high enough for such slags (Table 4). Nor are they crucible slags derived from re-melting smelted metal, again because of their very low iron content.

If it were not for the copper content which can reach as high as 5.7% of metallic copper in a red coloured slag one would be tempted to suggest that they were vitrified fuel ashes contaminated with soil or sand. The lime (CaO) content is more than adequate, and the alkali may have been leached out to some extent. It is in fact possible that much of the surrounding soil is contaminated with Cu ores and this is the cause of the copper content. If so, the 'slag' has been heated with sufficient fuel to keep the copper in the reduced state.

But such 'slags' could be formed by the heating of native copper in a crucible together with some dolomite gangue. In other words it could be a slag derived from the melting of native copper in a charcoal fire with a forced draught.

In any case the fire has been a very hot one, probably urged with bellows. Present slag melting points would be in the range 1400-1300°C but these would be reduced by higher original alkali contents. For example, a composition with 10% Na_2O, 61% SiO_2 and 28.5% CaO has a melting point of 1047°C[2].

Considering the existence of native copper in the vicinity, the presence of crucible sherds, and the possibility of tuyeres, there is little doubt that this material relates to a native copper melting technology using the furnaces as bowl hearths full of charcoal. Quite a lot of native copper has been found to contain substantial amounts of arsenic[4].

The raw copper and the artifacts are basically impure copper

Table 3

Slag Analyses – Ikawaten

	Site 193			
%	SP1	SP2	SP4	SP1 (inclus.)
SiO_2	42.5	38.7	39.5	0.45
CaO	37.3	10.5	37.8	0.71
MgO	10.6	13.2	9.8	5.9
Al_2O_3	5.5	15.1	6.4	nd
FeO	0.2	1.9	0.4	0.25
Na_2O	2.4	5.5	2.4	nd
K_2O	nd	1.5	0.1	nd
Cu *	nd	0.26	nd	93.5
MnO	nd	0.63	nd	nd
TiO_2	nd	1.5	nd	nd

* Metallic copper, not oxide.

with occasional natural high arsenic and iron contents. With two exceptions they are low in tin and unalloyed. The bracelet is a brass with lead and tin. This is a fairly typical assemblage from a copper producing site – the objects being made by the workers for their own use.

The other important feature of the area is its early dating sequence. In this respect it should be compared with early impure copper artifacts from Mauritania which have dates of 500 BC [14]. Clearly we now seem to have some signs of a Copper Age in West Africa.

Acknowledgements

I am grateful to Monsieur D Grébenart, Mme S Bernus and Mme N Echard for allowing me to examine this material and for their helpful discussions on the results.

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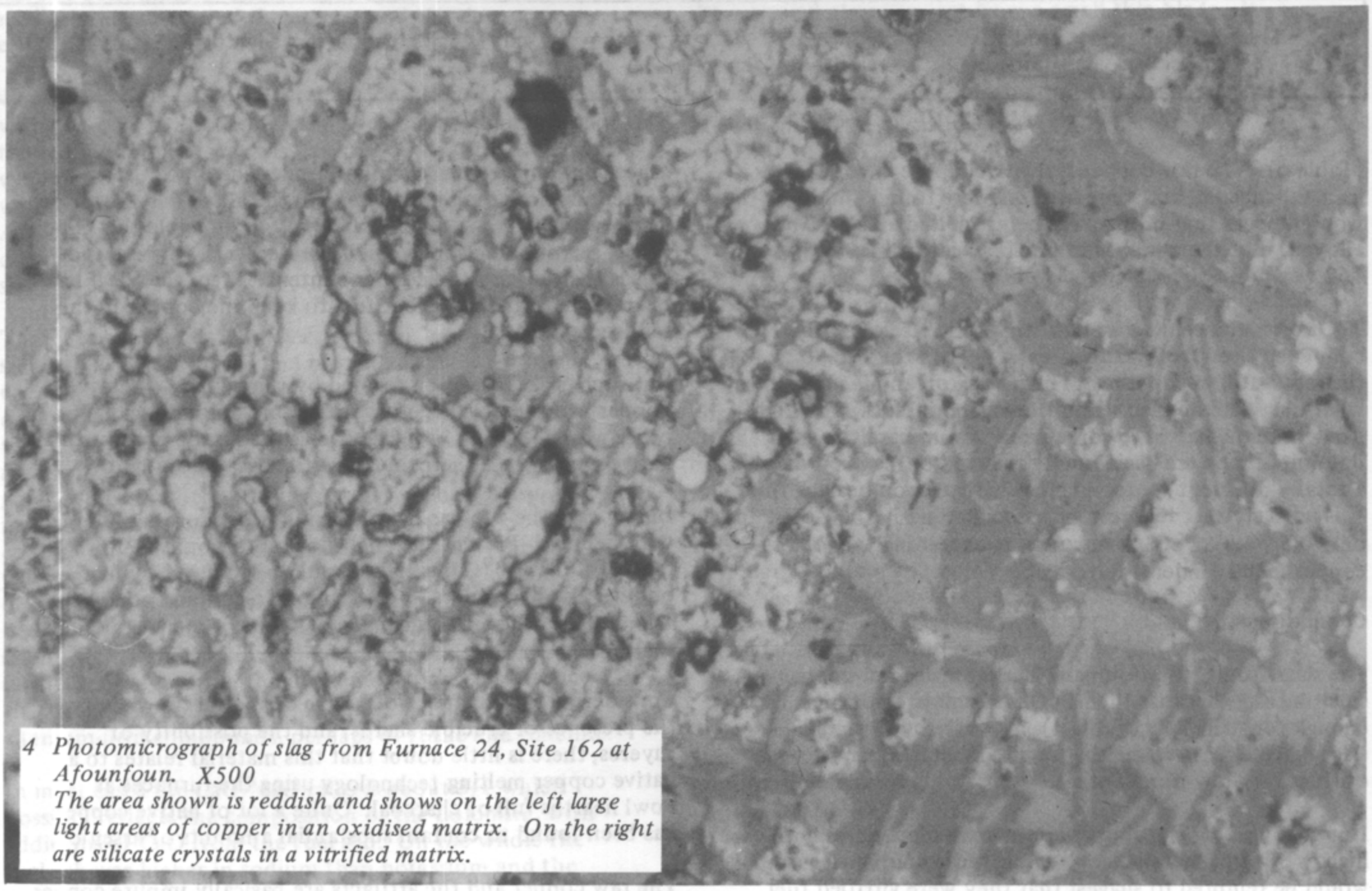

4 Photomicrograph of slag from Furnace 24, Site 162 at Afounfoun. X500
The area shown is reddish and shows on the left large light areas of copper in an oxidised matrix. On the right are silicate crystals in a vitrified matrix.

Table 4

Analyses of copper smelting slag, crucible slag and vitrified fuel ash (VFA) compared with raster analysis of slag from Afounfoun – Site 162.

%	Copper smelting slag – Timna 2[4] (12th cent. BC)	Crucible slag from York[8] (Roman)	VFA – Gt Weldon Roman[10]	Afounfoun, Site 162 (c. 800 BC)
SiO_2	40.2	57.1	61.0	45.4
CaO	9.3	3.0	3.3	27.9
MgO	0.5	1.73	0.02	10.2
Al_2O_3	2.2	19.6	16.2	7.52
FeO	43.3	8.6	17.1	1.70
Na_2O	-	-	1.77	2.26
K_2O	-	-		0.87
Cu	0.61	1.4	nil	0.95
MnO	-	tr	nil	0.30
TiO_2	-	-	-	0.70
S	0.10	-	-	-

- not sought

Table 5

Trace element composition of slags from the Agadez area of Niger (After Bourhis[11]) %

Site		Cu	Sn	Pb	As	Sb	Ag	Ni	Bi	Fe	Zn	Mn	SiO_2
Afounfoun 175:	F 6	∼3.5	0.001	0.02	0.003	0.001	0.003	0.007	0.002	XX	0.002	0.15	XXX
	F 8	∼1	0.001	0.005	0.002	0.001	tr	0.005	0.001	XX	0.001	0.15	XXX
	F 1	0.30	0.001	-	0.001	0.001	tr	0.005	0.001	XX	0.001	0.10	XXX
Ikewaten 193		∼1.5	0.01	0.003	0.005	tr	tr	-	tr	XX	tr	0.20	XX

Technique: Emission spectroscopy	∼ about
XXX Composition greater than 50%	- not determined
XX Composition less than 50%	tr less than 0.001%

Table 6

Composition of raw copper and copper-base objects from sites near Agadez

(After Grebénart[7])

Site and Object	Composition % Cu	Sn	Pb	As	Sb	Ag	Ni	Bi	Fe	Zn	Mn
Afounfoun											
162. Nodules of copper	91.5	tr	0.015	~1	-	0.015	0.01	0.001	~7.0	0.03	0.003
	98.8	0.001	tr	~1	-	0.015	0.001	tr	0.002	-	-
175	97.5	0.001	0.002	~2	-	0.08	0.005	-	0.4	0.002	0.20
175	98.7	tr	-	~1	-	0.02	0.002	-	0.005	-	tr
175 wire	99.8	0.005	0.001	-		0.01	0.005	0.015	0.01	tr	-
162 ring	(85)	~15	tr	0.25	-	0.002	-	tr	0.01	-	0.001
162 awl	(99)	tr	0.001	0.15	-	0.002	0.002	tr	0.50	0.002	0.001
162 bracelet	79.5	~3	0.6	0.10	0.015	0.02	0.008	0.025	0.05	15	0.001
Ikawaten											
193 Nodules of copper	95.5	tr	0.001	~1	-	0.03	0.008	-	3.5	0.005	0.05

( ) Calculated by difference

~ about

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Metallographic research on four pure copper flat axes and one related metallic block from an Eneolithic Italian cave

Leno Matteoli and Constantino Storti: Centro Studi Preistorici ed Archeologici di Varese

The flat axes were found in the cave **Bocca Lorenza** sited along the southern declivities of the mount Summano at the height of 387 m, near to Santorso (Vicenza).

The first researches were made in 1908 and the first flat axe (No 4393 – Figs 1 and 2) was found inside a more than 10 m high pile, made of enormous thrusted blocks.

The first studies of Prof A Broglio, and now the conclusive researches published by Dr B Bagolini, allow us to conclude that the cave of Bocca Lorenza could be an example of one frequented by Eneolithic people for a sepulchral purpose. So Bocca Lorenza is now included in the context of the small caves and the sepulchral shelters of Lombardia, Veronese and Trentino, due to the other discoveries which have occurred there.

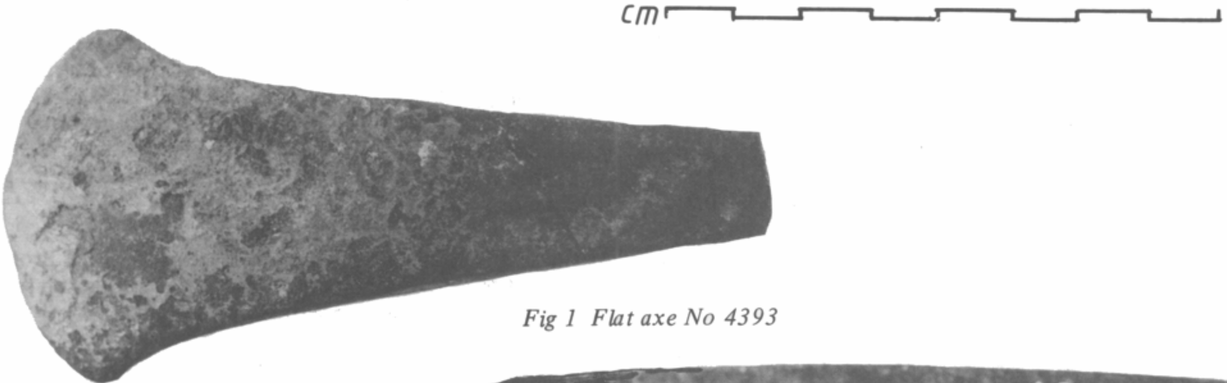

Fig 1 Flat axe No 4393

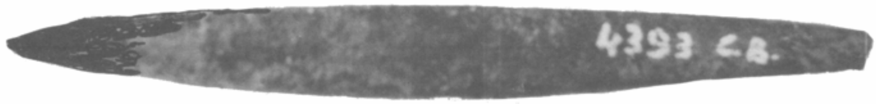

Fig 2 Flat axe No 4393 : Side view

Recently, in 1961, the researches started again and another two flat axes (No 7776 – Fig 3, and No 7777 – Figs 4 and 5) were found in a small untouched edge of a spoil bank, together with some pottery 'a bocca quadrata o quadrilobata'.

It appears from the analyses given in Table 1, the three flat axes No 7776, 7777 and 4393 are made of pure copper and it may be assumed that native copper had been used.

Fig 5 Flat axe No 7777 : Side view

Fig 3 Flat axe No 7776

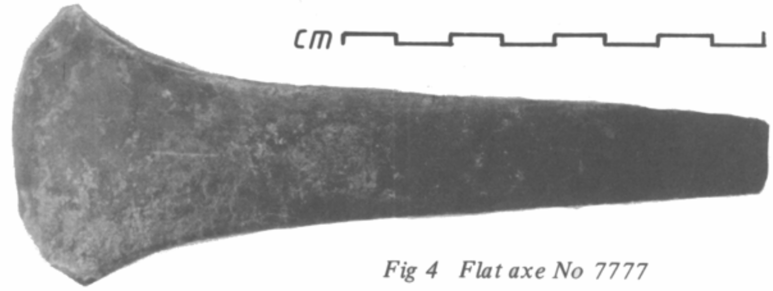

Fig 4 Flat axe No 7777

Element	**Axe 7776**	**Axe 7777**	**Axe 4393**	**Axe 613**	**Block (Massello)**
Cu %	Majority	Majority	Majority	Majority	62.68
Fe %	0.003	0.007	0.017	0.024	35.73
Ni %	0.009	0.011	0.008	0.021	0.032
Si %	0.021	0.006	0.006	0.011	0.034
Al %	0.003	0.002	0.01	0.005	0.008
Sb %	0.003	0.005	0.002	0.02	0.001
Pb %	0.001	0.001	0.001	0.045	0.002
Bi %	0.001	0.001	0.001	0.004	0.002
Sn %	0.001	0.001	0.001	0.007	0.009
As %	0.001	0.001	0.001	0.033	0.06
Mn %	0.001	0.001	0.001	0.001	0.014
Zn %	0.01	0.01	0.01	0.5	0.7
Ag %	0.5	0.5	0.5	0.5	0.5
Ca %	0.3	0.3	0.3	0.3	0.3
Mg %	0.3	0.3	0.3	0.3	0.3
Co %	0.01	0.01	0.01	0.001	0.3
Cr %	0.01	0.01	0.01	0.01	0.01

Table I

The total content of the impurities is lower than 0.05%, if we exclude silver[1]. These impurities are near the same values shown in Table II for the two English flat axes (9) and (9) published by Coghlan and Parker[2].

In the same table there are, for comparative purposes, the analyses of two other interesting copper artifacts, such as an Etruscan flat axe from Tarquinia (8) and another Irish axe (8).

Another confirmation of the native copper source of the three flat axes of Bocca Lorenza could be given by the comparison with the impurities present in a fourth copper flat axe (No 613 – Figs 6 and 7) analysed together with the other three.

The axe No 613 was found at Fontega, in a peat bog in the same Colli Berici; its shape is similar to the artifacts of Bocca Lorenza, but this last axe is unfortunately not so well preserved. For a proper comparison the analyses of Fontega are reported in Table I. In our opinion, though this axe comes from a very pure copper, it presents nevertheless a different and significant pattern of impurities such as zinc (0.5%), lead (0.045%), arsenic (0.093%), antimony (0.02%) and bismuth (0.08%). Also, the assessed presence of arsenic and bismuth leads to the possibility of smelting from an ore.

At the same time and for a proper comparison, Prof Broglio gave us a typical metallic block (Figs 8 and 9) that a farmer found just near the said cave of Bocca Lorenza.

Fig 6 Flat axe No 613

Fig 7 Flat axe No 613 : side view

Fig 8 Metallic block from Bocca Lorenza

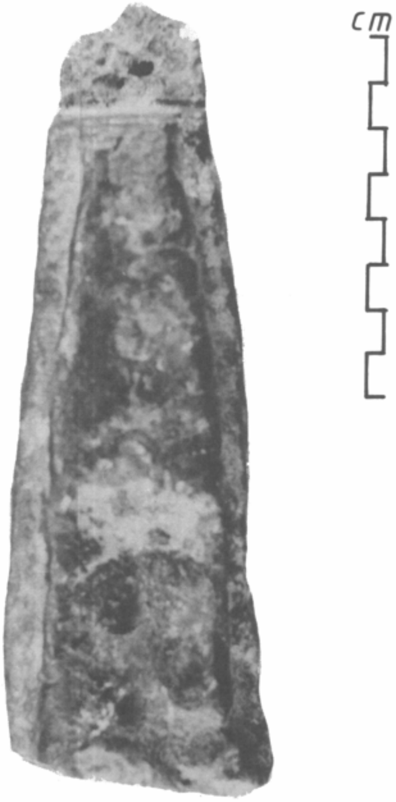

Fig 9 Metallic block from Bocca Lorenze : Side view

According to the analysis reported in Table I and made of course all together with those of the four said flat axes, the metallic block shows a strange composition, similar however to those of the prehistoric metallic blocks found, for instance, in the hoards and comparable to the block of Bocca Lorenza.

It is indeed an uncommon alloy due to the miscibility pattern of copper and iron both in the solid and liquid state.

The microstructure of the block confirms the practical insolubility of copper and iron in the solid state: in the distribution of these two elements is very heterogeneous (Figs 10 and 11). Beside a zinc content of 0.7%, they found 62.68% of copper and 35.73% of iron (Table I). The absence of sulphur could mean the use of a non-sulphurous copper-iron ore like for instance chrysocolla,ore deposits of which are located near Agordo (Belluno).

Metallurgical reduction of such an ore could have been obtained even in very ancient times, but we are surprised by the high iron content which should have been eliminated by a high oxidation followed by proper slagging[3].

The microstructure of the flat axes shows undoubtedly the fabrication techniques: melting in an oxidizing atmosphere due to the great amount of cuprous oxide in the microstructure, above all near the surfaces (Figs 12 and 13).

Though the direct determination of oxygen was not made, estimation of cuprous oxide in the microstructure allow to state that the oxygen content varies from a minimum of 0.01% in the main body (Fig 12) to a maximum of 0.04% in the areas near the surfaces (Fig 13).

In some external areas (Fig 15), the oxygen content reaches approximately the eutectic value (about 0.38%).

The oxidative atmosphere is probably due to the blowing of air through a tuyere necessary not only to reach but also to exceed the copper melting point; for the small furnaces had to be able to reach a temperature of 1200°C at least.

The high purity level of the copper is without doubt related to the oxidative atmosphere too, if we accept a high oxygen content especially in the surfaces.

Molten copper was cast in stone-moulds and these types of mould have been found in England. Using such moulds both the defects of casting, like blowholes or a large amount of cuprous oxide, are driven to the casting surface, from which they can be scraped off and then partially eliminated.

The microstructure indicates that the axes were probably hot hammered and forged, as the dendrites have been destroyed. The castings seem further well re-crystallized in form of uniformly fine crystals (Figs 14 and 15).

The absence of preferred orientation of the grains indicates that the metal was annealed and consequently recrystallized, probably during a natural cooling from the forging temperature.

In our opinion it is unlikely that the axes had been intentionally annealed in the modern meaning of this word, after having been hot forged; in such a case, a natural cooling from the forging temperature seems to be sufficient to attain the recrystallisation. As expected, irregular deformation is shown by the different grain sizes (Figs 14 and 15). Following upon recrystallisation, the grain sizes are a function of the deformation of the metal.

Locality	Unknown prob. British	England (Somerset)	Italy (8) Tarquinii	Ireland (8)	Lizard (9) Cornwall	Gwennap (9) Cornwall
Museum No.	D.M.1335 (Flat Axe)	80D (Flat Axe)	OA.59 (Flat Axe)	S.224 (Halberd Rivet)	(Native Copper)	(Native Copper)
Chemical %						
Copper			99.8	99.5		
Silver				0.18		
Spectrographic %						
Zinc	0.001	<0.001	n.d. (<0.005)	n.d. (<0.005)	n.d.	n.d.
Tin	0.0005	0.0005-0.0007	n.d. (<0.005)	n.d. (<0.005)	0.0005	0.001
Lead	0.01	0.01-0.03	tr<0.01	tr<0.01	n.d.	0.0004
Iron	0.002	<0.0005	0.01	0.01	0.0002	0.0002
Nickel	0.005	approx. 0.01	tr <0.01	0.01	approx.0.02	n.d.
Manganese	n.d. (<0.001)	<0.0001	n.d. (<0.005)	n.d. (<0.005)	n.d.	n.d.
Aluminium		<0.002	n.d. (<0.01)	n.d. (<0.01)	n.d.	tr
Silver	approx.0.005	>0.0006	0.04		0.002	0.003
Antimony	0.01	>0.01	0.04	0.02	n.d.	n.d.
Bismuth	0.002	0.001-0.003	0.0003-0.0005	0.008	n.d.	0.0001
Arsenic	0.01	>0.01	tr 0.01	tr 0.01	n.d.	n.d.
Silicon	tr approx.0.001	<0.001	n.d. (<0.02)	n.d. (<0.02)	0.01	approx. 0.1
Phosphorus	n.d.	n.d.	n.d. (<0.02)	n.d. (<0.02)	n.d.	n.d.
Cobalt	0.0005		tr <0.01	n.d. (<0.005)	n.d.	n.d.
Tellurium	n.d. (<0.001)	<0.0001	n.d. (<0.01)	n.d. (<0.01)	0.005	n.d.
Gold	n.d. (<0.001)	-	n.d. (<0.005)	tr<0.01	-	n.d.
Magnesium	n.d.	n.d.	n.d.	n.d.	tr	

Figures are percentages by weight –
n.d. – not detected; >– more than; <– less than; tr – trace.

Table II

Analyses of Axes and Native Copper

These microstructural observations are confirmed by the hardness, that varies from 56 to 78 HB, in different areas of the same axe; it is further confirmed that the metal is not in an 'as cast' condition but it has been hot worked.

As known, pure copper in the 'as cast' or the fully annealed state gives hardness readings lower than 50 HB and so we may say that the axes seem to have been naturally cooled, starting from the working temperature and not annealed according to a modern meaning of the word[4].

Anyway, comparing to available analyses, first of all to the mentioned British flat axes, we are able to indicate that the three axes of Bocca Lorenza No 7776, 7777 and 4393 were made of **native copper**; a few doubts exist regarding the Fontega flat axe, No 613, which could have been made by the smelting of a non-sulphurous ore like chrysocolla, as pointed out above.

The microstructural interpretation allows us to state the following main steps of fabrication.

1 Melting in an oxygen rich atmosphere.

2 Casting in a stone mould, associated with the so called open mould method of casting.

3 Hammering and probably hot hammering, followed by natural cooling.

Acknowledgments

The authors wish to acknowledge the help received from Prof A Broglio, University of Ferrara, who sent us all the artifacts and took into consideration our investigations; and Dr B Bagolini, who gave us the conclusive dating of the axes (See 'Il neolitico e l'eta del rame-Ricerca a Spilimberto - San Cesario 1977-1980. A cura di B Bagolini. 1981). Our thanks are similarly due, with much gratitude, to the Istituto di Ricerche Breda and to Dr A Bozzolai for much help with analyses and the other determinations.

Notes and References

1 Sensitivity limits of the spectrograph used are as follows:

Fe-Ni-Si-Al-Sb-Pb-Bi-Sn-As-Mn	: 0.0005%
Zn-Ag-Co-Ca-Mg-Cr	: 0.001%

Due to non-availability of standards for Zn-Ag-Ca-Mg-Co-Cr these analyses are only semiquantitative.

2 Metallographic Research as a Museum Aid. An examination of two pure copper flat axes, by H H Coghlan and G Parker. The Borough of Newbury Museum, Newbury, 1969.

3 This is very interesting subject, which needs a complete investigation. We hope to be able to publish the remains of a prehistoric furnace and related copper slags found at Pergine (Trento) some years ago.

4 The results of the analyses and the interpretation of the micrographs here published have been made by the first author.

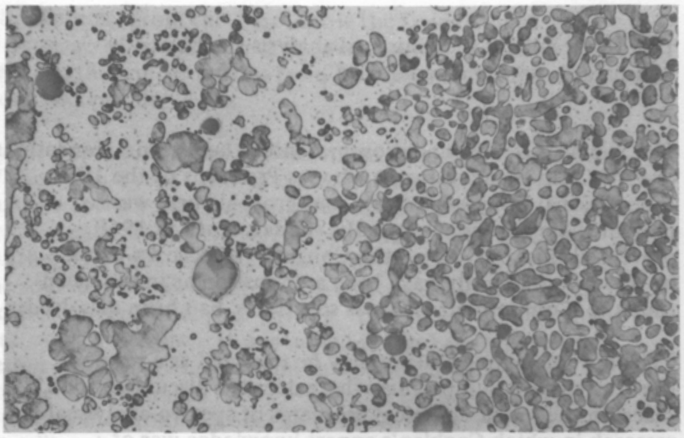

Fig 10 Metallic block from Bocca Lorenze : Grey elements are iron inclusions. Heterogeneous structure X 50

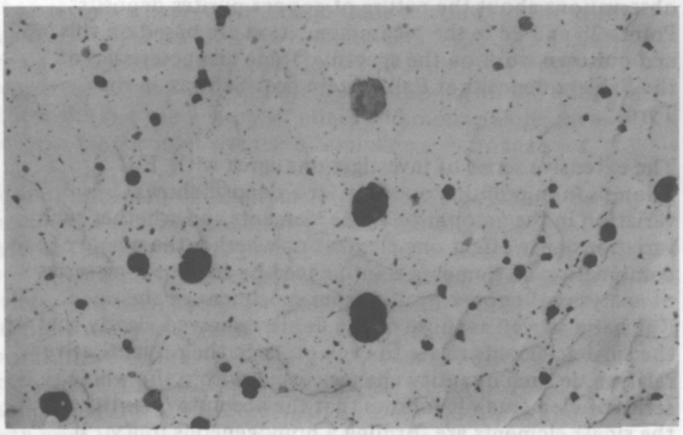

Fig 11 Metallic block from Bocca Lorenza : Another zone of the metallic block shown in Fig 10. Fewer iron inclusions. Remarkable heterogeneity. X 100.

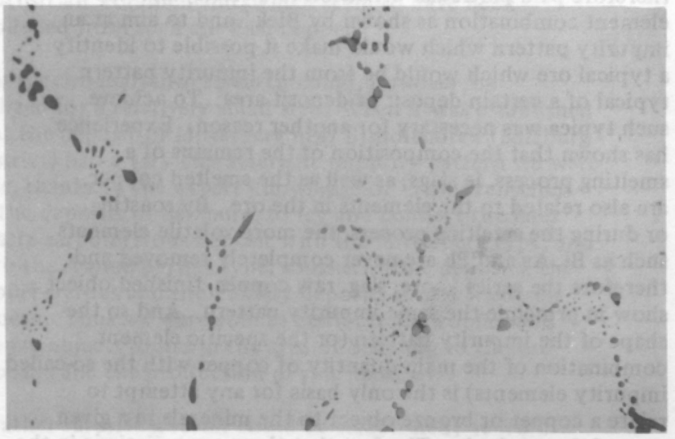

Fig 12 Flat axe No 7776: Cuprous oxide network according to eutectic texture. Unetched. X 200

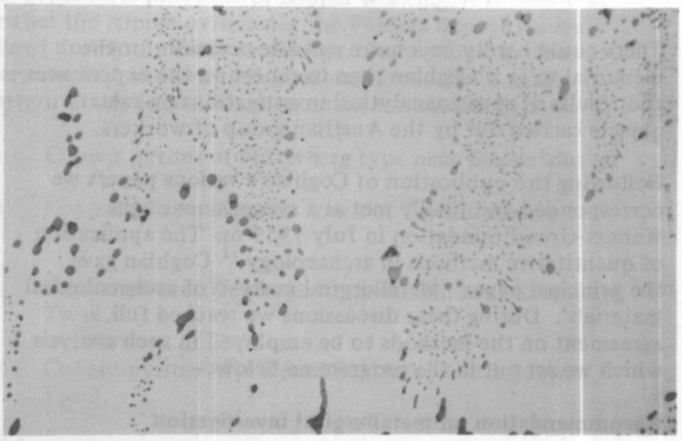

Fig 13 Flat axe No 7776: A layer nearer the surface. Cuprous oxide texture similar to Fig 12. Unetched. X 200.

Fig 14 Flat axe No 7776: All practically equiaxed crystals. Many twinned crystals that show plastic deformation of the material. Few cuprous oxide inclusions. Etched; X 75.

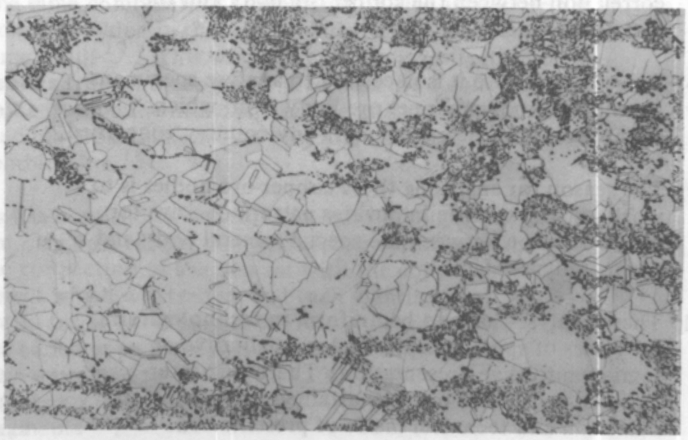

Fig 15 Flat axe No 7776: Surface layer. Much cuprous oxide. Grains smaller than Fig 14. Twinned crystals more evident. Etched. X 75.

Twenty five years of spectroanalytical research in Austria

R Pittioni

There could hardly be a more suitable occasion for the memorial to H H Coghlan than to report on the experiences and results of spectroanalytical investigations on metal objects carried out by the Austrian group of workers.

Following the publication of Coghlan's various papers we corresponded and finally met at a symposium of the Wenner-Gren Foundation in July 1959 on 'The application of quantitative methods in archaeology.'[1] Coghlan gave the principal paper: 'Metallurgical analysis of archaeological materials'. During these discussions we reached full agreement on the methods to be employed in such analysis which we set out in the programme below:-

Recommendation on metallurgical investigation

We feel that research in various countries of Europe lacks adequate co-ordination to direct research projects toward scientific results based on a complete knowledge of the general European problem. We visualize two orders of research:

1 **Technological-metallurgical work**

Here we are dependent upon the science of metallurgy **sui generis.** We can only request that the results of scientific experts shall be given to us in an appropriate form to meet our requirements. These cover all technological processes (on the one hand, as applied to non-ferrous metals, on the other, to the ferrous metals).

2 **Spectroanalytical-metallurgical work**

Here we are not dependent on the science of metallurgy **sui generis**, but we are using a modern branch of chemio-physical research for purposes of archaeology and the history of copper. Therefore, archaeology is directing research work in this field. The aim of this research has been discussed in the following terms:-

a) For the history of copper, the first essential is the correlation between the copper ore body and the metallic artifacts.

b) To get a firm base it is necessary to analyse specimens from every known copper ore body from which suitable ore may be extracted in any country concerned.

c) The reason for analysing these copper-ore bodies is to work out the specific impurities pattern decisive for the correlation between the special mineral body and the metallic artifacts.

d) These analyses have to be uniform in technological processes of spectrography and in qualitative or semi-quantitative presentation. Therefore, international agreement must be attained upon limits of detection and technical mode of presentation.

e) Our proposals stated here are in no way intended to interfere with the activities of any regional group of research workers, but they are offered as a guide for international collaboration, with the aim of insuring that the results of metallurgical analysis shall be truly comparable within all countries.

The Wenner-Gren Foundation presented these recommendations to Prof Carlo Blanc in Rome who, as President of the 1962 International Congress for Pré-and Protohistory, was to present them for discussion. His sudden death in 1960 prevented this, but even if the Congress had known about it, there would hardly have been a discussion as in the meantime the 'Comité pour analyses spectrales' had been dissolved.

The above recommendation may be regarded as a result of the Wartenstein Symposium where detailed discussion took place on the methodological problems of spectro-analytical research in which Coghlan's expert knowledge was of decisive influence. From the results of my own work I was able to summarize (already in 1958), the methodological foundations for an 'indirect mining-research' and to take into consideration the paper by F C Thompson[4] and his observations about the nature of copper pyrites deposits[5]. Points 2b and 2c in the recommendation are based on this and our own work on the spectrographic characteristics of the **Fahlerz** deposits at Falkenstein near Schwaz in the Tyrol[6].

The extensive series of investigations agree with F C Thompson in pointing out how far a deposit shows variation in the amount of single elements and whether such variations only effect one element or whether the whole of combination of elements is influenced by it. The long series of analyses of copper pyrites from specimens of the Kelchalm as well as those of the **Fahlerz** showed clearly that the single elements relate to each other in their quantitative relation, ie such quantity changes occur within the whole series of elements. It follows that the absolute quantity of the single elements are forming a homogeneous unity. If the spectro-analyses of an object shows that the share of an element is unusually high, disturbing the inner unity of an element combination, it will show the intentional addition of such a metal constituent. In all our investigations we therefore paid particular attention to a clearly defined element combination as shown by Biek[7] and to aim at an impurity pattern which would make it possible to identify a typical ore which would be from the impurity pattern typical of a certain deposit or deposit area. To achieve such **typica** was necessary for another reason. Experience has shown that the composition of the remains of a smelting process, ie slags, as well as the smelted copper, are also related to the elements in the ore. By roasting, or during the smelting process, the more volatile elements such as Bi, As and Pb are never completely removed and therefore the series – ore, slag, raw copper, finished object – show in principle the same impurity pattern. And so the shape of the impurity pattern (or the specific element combination of the main quantity of copper with the so-called impurity elements) is the only basis for any attempt to relate a copper or bronze object to the minerals in a given area of the ore body. The fact that there are variations in the pattern of each element is a warning against requesting absolute quantitative values for each element. Semi-quantitative data within a single element analysis is adequate for such relationships.

To establish a valid impurities pattern it is essential to have a comprehensive table of ore analyses, and an attempt should be made, to assess as far as possible, the depth of the deposit in question. Such a series would then make it possible to work out an average analysis which would take into account the established variations in detailed analyses.

The examples from the Tyrol show the fundamental difference, when comparing the two average analyses, between the copper pyrites from Kelchalm and the **Fahlerz** from Falkenstein[8]

By a comparison of the analysis of the objects, ie the bronzes of the north Tyrol Urnfield culture, it was established that the overwhelming majority of these bronzes were neither made from Kelchalm copper, nor from **Fahlerz**. Further extensive investigations have finally shown that the source of the raw material was a copper smelted from a different type of copper pyrites. This type occurs in the area west of Schwaz. It was mined in the Late Medieval period and the ore heaps from this period have yielded sufficient ore samples to show that this ore was the main source of the bronzes from the Urnfield culture of the early 1st millennium BC.

The Medieval mine is known as the Alte Zeche/Bertagrube, after which we named this type of north Tyrol copper pyrites. From the spectroanalytical investigations that followed we get an idea of the production and trade relations of the north Tyrolean copper trade in the last millennium BC. This has largely been possible through the active support of Ernst Preuschen[9] whose wide knowledge concerning all the questions of deposits and the history of mines and mining alone gave the basis for the intensive use of emission-spectroanalyses.

Without information on impurity patterns it would not be possible to reach any conclusions as to the origin of the raw material for the production of copper and bronze objects. Even if, with the aid of spectroanalysis, one or more impurity patterns had been established, nothing could be learned without the knowledge of the characteristics of the deposit. For this reason it was disappointing for us to be unable to locate the position of the origin of what we termed 'East-copper' for lack of ore analyses from Slovakian and north-west Hungarian deposits, in spite of a comprehensive impurity pattern obtained through a large series of metal analyses[10]. This is unfortunate as it was the time of intensive production belonging to Reinecke BA A, and later, as is testified by the large number of **ringbarren** found in Austrian Voralpenland, which seem to have been produced from such an 'East-copper'[11].

Our spectroanalytical research could, however, be utilized for a relatively small area. When it was established that the deposit of Mitterberg near Bishofshofen (Salzburg District) had a very characteristic impurity pattern we were able, thanks to the expert knowledge of Ernst Preuschen of the deposits of Salzburg, to try and connect the later quartz-carboniferous deposit with the Mitterberg type, and with the Alpine pyrites type, southern zone deposits, the copper-pyrites and the **Fahlerz** deposits of the Niederen Tauern. Thus we were able to attribute the copper and bronze objects found in the area of Salzburg to the ore deposits and the production of raw material.

A rather surprising result could be established; ie from 269 objects 196 had been produced from the copper of the Schwazer Bertagrube and only 72 objects from the copper deposit of the Salzburg area[12]. This raises the question of where the produce of Mitterberg was traded. Typological information points to trade with Central and North Germany, as well as areas further north, ie Denmark, South Sweden and South Norway.

For various technological reasons it is not possible to carry out a test based on our analytical method in the above countries. To summarize the results of our research regarding the prehistoric processes of copper working, it is clear that neither the Alpine pyrites nor the **Fahlerz** deposits were mined during the Early Metal Age. Only copper pyrites were smelted and worked. Evidence from the impurity pattern shows four different sources for copper pyrites:-[14]

a) Copper pyrites of Mitterberg type near Bischofshofen

b) Copper pyrites deposits south of Bischofshofen.

c) Copper pyrites Kupferplatte-Kelchalm near Kitzbühel, Tyrol.

d) Copper pyrites Alte Zeche Bertagrube near Schwaz, Tyrol.

All four copper pyrites – according to scientific knowledge of deposits – belong to the Alpine family. Apart from their general basic conformity they show individual differences which can only be worked out through detailed investigations in order to achieve average analyses with regard to quantitative variations of the single element.

The experiences gained in this way could be more useful if they included the impurity patterns of the **Fahlerz** mined in Medieval times in Rehrobühel (Röhrerbichl) near Kitzbuhel, Tyrol. The starting point were the assay crucibles of which 4 were found in Kitzbühel. These are small conical shaped bowls (called by Agricola 'Scherben') in which a small amount of ore was weighed and smelted in an assay furnace[15]

With an addition of lead, the 'Saiger' process was carried out on a small scale, in order to establish the silver and copper content of the ore. The remains of dross found in the crucible contained Ag, Sb and Zn, typical of **Fahlerz** with the intentional addition of lead. By this experiment it was possible to show the impurity pattern of **Fahlerz** of the Röhrerbichl deposit. This result was confirmed by the analysis of the smelting crust of a second crucible from Kitzbühel[16].

The same combination of elements on five assay crucibles from Saalfelden in the Salzburg district gave basically the same result[17]. This was, however, an investigation of **Fahlerz** from the Leoganger area; for the **Fahlerz** of the Falkenstein mine near Schwaz, the analysis of such assay crucible drosses has shown basically the same element combination[18]

As has been shown above, the similar impurity pattern of ore, slag, raw copper and finished object offered the basis for the connection of the deposit with the copper or bronze object which was traded, and such identification could be useful for another metal. We refer to the lead which was imbedded in an ingot from a hoard from Miljana in Croatia. This was dated to Hallstatt B (10th – 8th century BC). This hoard also contained 21 whole bun ingots and several fragments[19].

The numerous ingots belonging to the Urnfield culture are usually bun-shaped and differ from those of the EBA, ie BA Reinecke A which were flat-shaped. The Miljana ingots are cone-shaped, which can hardly be the result of a smelting process. In one of these ingots the top of the cone was damaged and revealed a core of lead enclosed in a copper/bronze envelope. The impurity pattern of the lead showed a high content of Ag, Cu and Sb. The envelope of this lead core was of bronze[20]. These elements pointed to a certain deposit and it is possible that the galena deposit of Littai/Litija near Laibach/Ljubljana was the source of the Miljana lead.

The experiences gained by the miners of antiquity in copper mining, working and smelting formed the basis for the extension of their activity in lead mining and, almost at the same time, the mining of iron ores[21] in North Tyrol. These deposits in the Late Carboniferous Quartz are rich in iron ores, sometimes exceeding those of copper pyrites, which would arouse the interest of the workers and draw attention to the possibility of the extraction of the iron which otherwise would go into the slags. Such observation throws a significant light on the problem of the origin and the beginning of iron production in the Alpine area.

Such assumptions are based on the analysis of an iron pin which was found in Tomb 1 of an Urnfield cemetery in Kitzbühel-Lebenberg. This analysis pointed to a connection with the Later Carboniferous Quartz deposits of the Kitzbüheler mine and has been confirmed by further slag analyses for the Late Medieval period and after[22]. The deposit of Gebra near Aurach must also be considered. According to O M Friedrich it belongs to the group Annaberg-Werfen[23].

Further evidence for Medieval and later iron mining comes from a slag analysis of Jochberg near Kitzbuhel[24] which can probably be related to iron mining at Luegegg. Another iron smelting place in the neighbourhood of St Johann in the Tyrol[25] might belong to iron working of AD 1535 for which we have documentary evidence. This confirms that spectro-analyses for the investigation of deposits in the Later Carboniferous Quartz can be pursued successfully. How far this is valid also for iron ores and their products, from other deposits, has not yet been investigated.

Finally it must be mentioned that the use of emission spectro-analyses of gold has provided some remarkable results. Ten native gold specimens from the deposit of the 'Goldenen Viereck' in Transylvania and a similar specimen from the Schemnitzer area of Slovakia were analysed for their composition for the first time.

The copper content of the gold gave an impurity pattern which proved to be significant for its origin. It could be shown that it was identical with a **ringbarren** from a Transylvanian find[26].

Unfortunately it is not possible, for non-scientific reasons, to do further research, although more detailed knowledge of Transylvanian gold and its impurities would be of great value to the specialist. Even a catalogue of the Transylvanian gold alone would be useful since the investigation of gold objects has hardly begun. It is largely based on guesswork which is also true of the prehistoric and Roman gold mining of the Tauern. The Viennese group has too small resources to make a comprehensive study of the gold impurity pattern of the Tauern.

Investigations on slags from the Hofgastein revealed an interesting impurity pattern[27] without however showing a general connection with the Tauern gold. A gold specimen from Radhausberg and one of alluvial gold from Salzach proved to derive from smelting debris because of the mercury content[28] but could give no clear indication of a possible source. The Viennese group has every intention of following up their investigation of an impurity pattern for the Tauern gold, depending on whether it will be able to collect sufficient specimens from deposits.

Looking back over 25 years of research it can be stated that the Viennese group has chosen the right method which has led to important results of our knowledge of socio-historical understanding. We can state with some satisfaction that the investigations carried out by the Max Planck Institute for Nuclear Physics in Heidelberg have followed exactly the same course in their investigation of the origin and production of antique Greek coins which enabled them to show that these coins were made of silver coming from the mines of Laurion[29].

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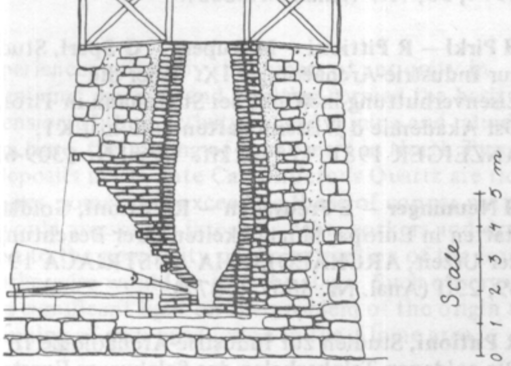
Translated from the German by Elizabeth Tylecote.

Early Blast Furnace News



1. **Northumberland.** Dr Stafford Linsley has discovered an Elizabethan blast furnace, with a rectangular crucible, dated 1550 – 1570, near Stocksfield. Further information will be published in due course.

2. **Ross Shire, Gairloch.** The earliest known Scottish blast furnace is situated near Poolewe, and was in operation from about 1610 to 1670.

Following the Elizabethan restrictions on the cutting of timber to produce charcoal, the smelting of the rich Cumberland and Lancashire hematite ores moved north into Scotland. Well known 18th century blast furnaces exist at Bonawe,Furnace and Glenkinglass but, nearly a century earlier, smelting took place around the shores of Loch Maree and on the river Ewe, and this last site, known as A **Cheardach Ruadh** – the 'Red Smiddy' – was excavated by a team headed by John Hume (Strathclyde University) and C J Tabraham (Inspectorate of Ancient Monuments, Edinburgh) in September 1980.

The base of the furnace was exposed. It was 5.9m square with a rectangular hearth 1.7m by 1.6m. The blowing and tapping arches were identified. It was water wheel blown.

A model exists and can be seen in the Gairloch Heritage Museum. In the churchyard nearby is a memorial stone to John Hay, the last manager of the iron works, and at the north east end of Loch Maree is the **Cladh Nan Sasunnach'** or Englishmen's burial ground. Skilled Cumbrian workers had been brought to operate the works, and one or two families still living in the area have names originating from Cumbria. This information is by courtesy of Sheriff W R M Murdoch, of Gairloch, and from an interim report by Messrs J R Hume and C J Tabraham.

3. **Shropshire.** A 17th century blast furnace has been located at Tilsop, south of Ludlow and Cleobury Mortimer, as the result of work done on manuscripts by Dr Kenneth Goodman while producing his thesis *'Hammerman's Hill. The Land, People and Industry of the Titterstone Clee Hill Area of Shropshire from the 16th to the 18th centuries'.*

Unfortunately he died after finishing his thesis, and since then no further work on the blast furnace site has been carried out.

Large mounds of slag, clinker and ash have been found in the heavily wooded valley of the Corn Brook. Plentiful supplies of wood for charcoal existed, and the richest deposits of iron ore at this period were just over a mile upstream. A small furnace pool still exists.

Strangely enough it is the paucity of documentary evidence which has precluded reference to the furnace in either local histories, or the history of the charcoal iron industry. The site has not been investigated, and it is not marked on ordnance maps, although a much smaller furnace, which was built about 1795, two miles upstream is noted. A grave slab in **Coreley** church, dated 29 April 1684, refers to '. . . . of Tilsop Furnace' and there is a parish register burial entry in **Milson** church, the next parish, dated 8 December 1687 '. . belonging to the Farnace'

It would appear that, from ironstone deliveries, the furnace was established some years before 1662 – replacing the furnaces at **Cleobury Mortimer** which ceased to work in the late 1630s – and closed down some time between 1705 and 1708, when the owner began to transport the ironstone of the district to his own furnace at **Bringewood**. This synopsis has been made possible by courtesy of Dr M D G Wanklyn, of the Polytechnic, Wolverhampton, who prepared Dr Goodman's material for publication in 'West Midlands Studies' Volume 13, 1980, on the suggestion of Margaret Spufford of the University of Keele.

4. **Vale of Neath.** One week after Harry Green's article **'Melin-Y-Cwrt Furnace** – Earth, Air, Fire and Water' in Transactions of the Neath Antiquarian Society 1980-81 was published, Harry Green died.

It is therefore all the more salutory to read, on the fifth page – 'The survey was prompted by a lucky find – if anything can be called lucky if it leads to quartering one side of a cwm choked with gorse and bracken, or scrambling through recently felled forest in the rain. These tasks belong, properly, to youth, and for us youth is a leat that's long run dry'.

The Melin-y-Cwrt site is a spectacular one made famous by paintings by Wood and Hornor, some time after 1808, showing a huge waterfall adjacent to a large overshot wheel and a works. In fact the two are not connected, and Mr Green's paper is the story of his researches into the leats which carried water power to the blast furnace for its two periods of operation.

The furnace 'began to blow' on October 6, 1708, with charcoal as fuel. Then about 1785, the changeover to coke as fuel took place, but the works closed in 1808.

Mr Green explored the leats both on the ground – as referred to above – and through many documents, maps and manuscripts. He took many photographs and produced a definitive plan of the water power resources over the period 1708-1808 .

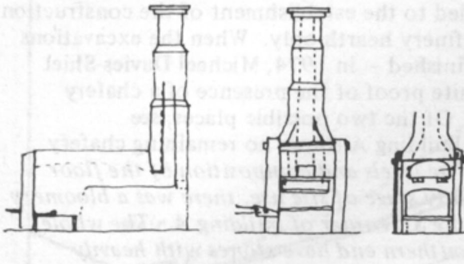
The description is not too easy to follow and the interpretation of the remains on the works site is difficult. There appears to be an 'air' furnace – just adjacent to the blast furnace – which came into operation with 'the finery and foundry' after the 1795 conversion to coke-iron, but how this operated is far from clear. There is no evidence of a forge.

'No precise cause for the failure of the converted works and its closure in 1808 has been determined' – but – 'the coke iron works which achieved the greatest efficiency were those which used Watt's steam engine to produce blast. Perhaps Melin-y-cwrt, which lived by water, was killed by steam'.

Letters to the Editor

Dear Sir

Reverberatories and Fineries



In an article in JHMS 15.2, pages 94 - 100, Professor D G Tucker and Peter Wakelin describe two very interesting manuscripts.

They refer to the possible use of reverberatory furnaces in iron making but consider the description given in the MS puzzling. They mention Cort's and Onion's methods, the Cranage brothers and the potting process; but neither seems to fit.

I imagine that the furnace referred to is not a reverberatory furnace proper. I presume the description to refer to a charcoal finery hearth used with the 'stamping refinery' that was in use at South Wales works at the time.

We have a description of this type of hearth, with sketches, from a travel diary of Gustaf Ekman, dated 1828.

From the sketches it will be clear that the finery hearth does look like a reverberatory furnace. In fact, however, the reverberating arch is used to obtain efficient pig iron preheating; but the metallurgical processes all took place in the charcoal hearth itself.

Ekman's descriptions of the process and hearth are available in Swedish literature.(1). The main points are translated below:

When visiting several South Wales ironworks early during his English study tour, autumn 1828, Ekman seems to have been interested particularly in puddling methods. Later on, he however became less interested in this technology, presumably because he found that puddling was less suited to the Swedish circumstances than fining in (charcoal) hearths. Instead, he became much more interested in a hearth fining method in use at several ironworks he visited in South Wales. This method, locally called 'stamping refinery' was the process used for the production of billets for tin plate manufacturing (the same process C.Fr. Waern introduced at Backefors, Sweden, in 1829, with the help of smiths from South Wales).

Ekman did travel from South Wales, via Birmingham, Sheffield, Leeds, the Newcastle area, and Scotland to Ulverston(e), Lancashire. Here he found the same method of charcoal fining of pig iron in an efficient hearth. In fact, the full knowledge of producing bar iron by fining of (charcoal) pig iron in a charcoal hearth was available here.

In this 'Lancashire method' the hearth and the working procedure are similar to those observed by Ekman in South Wales. The South Wales method is said to descend from the Lancashire procedure.

In Ulverston, charcoal pig iron was used, in the form it came in from the blast furnace . . . sows. In Wales, however, coke pig iron was used. This had too high a Si and C for direct fining either in a puddling furnace or in a finery hearth. The pig first was refined. To this purpose it was run into a so-called refinery hearth, directly from the blast furnace. Here it was freed from much of its Si and some of its C. The refinery hearth used coke as a fuel; and ample blast. The end product, so-called fine metal, was brought into the finery hearth, either liquid or as solid lumps. The lumps were loaded on the bridge behind the hearth proper, for preheating by means of the exhaust gases.

In Ulverston, the more viscous, non-refined charcoal pig was used. This was fed in sows (gueuses), from behind the hearth. The sow slowly passed through the reverberatory chamber behind the hearth, where it was preheated.

There were other differences in procedure, too. The forges in Wales mainly produced billets. To this end the loup from the finery hearth was stamped into a 'cake', divided into smaller parts and then these parts were fagotted (ie bundled, welded together and drawn into a rough billet). The loups produced in an Ulverston forge were divided after shingling into several parts, each suitable for rolling. These were then reheated and rolled into bar.

For further details of the introduction of this hearth fining method in Sweden, I refer to my article in JHMS 15.2, pages 63 - 87.

Alex den Ouden

(1) Gustaf Ekman, Svenska jarnhanteringens nydanare for 100 ar sedan; G Ekamn; Jernkontorets Berghistoriska Skriftserie N:r 12; Jernkontoret, Stockholm, Sweden; 1944.

Dear Sir

The Austrian *Refinery*

Jars mentions in his 'Voyages Métallurgiques'[1] the use of a *Refinery* in Austria about 1750. This is a communication that can provoke some speculation as I hope to show.

Up to the period of about 1750, Austrian ores in the Styrian area were reduced mainly by Stucköfen[2]. In a Stucköfen the main product, called Massl or Stuck, is a kind of bloom, with C in the region of steel. Apart from the Massl some liquid pig iron, called Graglach[3] or Kraglach[4] was formed.

The C contents of the steel of the Massl varied considerably within the Massl and steel had to be fagotted and perhaps partly fined in a German hearth ('Garben').

The Kraglach had to be really fined – in the same German hearth – usually into wrought iron ('Hammereisen').

From about the 1750s Austria's iron production switched over to Flossöfen, ie to blast furnaces. These produced pig in thin rectangular plates, called Flossen[3]. The Flossofen used charcoal and cold blast. The pig will have been relatively low in Si.

The metallurgy of the fining process is admirably summarized by Morton[5]. Two stages exist – in one hearth. The first is the so-called *Refining* stage, in which Si is oxidized during the melting down of the pig iron – while no decrease in C appears. The second stage is the fining proper, in which C is decreased partly by oxidation with blast and partly by slag-metal interaction.

Now Austrian Flossen did not have an exceptionally high Si. The Walloon finery as used in England on charcoal (tough) pig had always coped with that kind of Si. Only when coke pig started to be used --with its higher Si -- was it found necessary to use a separate *Refinery* to decrease Si prior to fining[6].

So there is no reason to suppose that the German hearth could not cope with the Flossen.

What then could have been the reason for the use of the tandem:

Refinery + German hearth

The German hearth process uses the one hearth not only for fining; the blooms produced by hammering the fined loups are also reheated in the same hearth. The hammering of the blooms into bars takes place during the melting down of a new batch of pig, ie during the *Refining* stage. The German forge smith thus did not have much opportunity to guard the melting down stage. Usually the slag activity was adjusted prior to the second stage, the fining proper, by the addition of sand and/or hammerscale. The iron and steel in this way produced from Graglach was considered to be inferior[4]. Now, however, with the Flossofen, all available raw material had to be fined to be useable at all. As the product required was decidedly more steel than wrought iron, not only the fining process (stage 2) had to be more carefully controlled, but also the slag-condition after the *Refining* stage (stage 1)..

My hypothesis is that the smiths could not keep the slag sufficiently well under control -- when having to hammer bars simultaneously -- to make the original German forge work-pattern feasible. Thus, a separation became necessary for the same reasons as in the Walloon process:

process-control

They could of course have chosen the Walloon type of working, with separate reheating . . . but it appears they went the other way, separating the *Refining* and the fining proper, thereby perhaps showing the way for the -- later -- English difficulty!

Alex den Ouden

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R F Tylecote: History of Metallurgy; Metals Society; 1976. p 108.

2 In Karnten the last Stuckofen was blown out 1775; in the Vordernberg-region 1762; see

Manfred Wehdorn; Die Baudenkmaler des Eisenhutten-wesens in Osterreich; VDI-Verlag; 1977p 32.

3 Manfred Wehdorn; op cit; p 34.

4 Josef Zeitlinger; Jahrbuch des Vereines fur Landeskunde und Heimat-Pflege im Gau Oberdonau; 91 Band; Winner Verlag, Linz; 1944; p 84.

5 The description given is for the Walloon finery, but it holds as well for the German hearth, in:

George Morton; Bull HMG; 5 1 (1971); p 24.

6 As this -- in the beginning -- was also charcoal fired, the saving of charcoal by using coke in the blast furnace certainly was annulled!

Dear Sir

Stony Hazel -- A Unique Blend of German and Walloon Forge?

As reported in 1970[1] the excavation of the Stony Hazel wrought iron forge led to the establishment of the construction and position of the finery hearth only. When the excavations were stopped -- unfinished -- in 1974, Michael Davies-Shiel had not found definite proof of the presence of a chafery hearth on the site[2]. Of the two possible places, see *figure 1*[3], the forge building A shows no remaining chafery hearth, although: *'The levels and composition of the floor suggest that, at an early stage of site use, there was a bloomery or forge occupying the SE corner of building A. The whole of the walls at the southern end have stones with heavily burnt surfaces facing inwards, suggesting total rebuilding, using stones from a previous (?) furnace'*[4]. The second possibility is that the chafery hearth was located at the northern side of building B. At the time of the 1970 article, this building was not yet excavated, in fact, its excavation was never finished. In my opinion, the position of building B with regard to the watercourse makes this second possibility highly improbable. It is interesting to see how closely the lay-out of the forge building A resembles that of the remaining *German* forge at Havla in Sweden. See *figure 2.* Also it is interesting to compare the plans of the (Walloon) finery hearth in England[5] and the Low Countries [6] with those of a German hearth in Austria[7] and the Stony Hazel hearth[8], see *figure 3.*

There are two main differences between the Walloon type and the German type of wrought iron bar forge. The Walloon forge comprises two hearths, a finery and a chafery. In the first pig iron is fined into a loup, which is hammered into one (or more) blooms. These are -- still hot -- reheated in the chafery hearth before being hammered into bars. The German forge has just one hearth in which the blooms are reheated *and* fining is executed. Hammering of the reheated blooms into bars occurs during the melting down of a next load of pig iron prior to the rabbling of the loup, ie during the first stage of the fining process, the so-called *refining stage* (see [9] for a definition of terms).

Ore, sand, hammerscale or iron-rich slag were used to obtain a working slag of correct reactivity for the second stage of the fining process, the *rabbling stage*, in the German hearth[10]. In the Walloon process, the use of ore *'had been forgotten until a Samuel Lucas re-introduced the method in 1804'*[4].

The second difference between the two types of forge is in the way of feeding pig iron into the (finery-) hearth. A Walloon finery uses long 'gueuses' or sows of pig, gradually fed into the hearth from behind, through a pig-hole. In a German hearth, pig is buried under the charcoal batch-wise, in small pigs.

Why now is the hearth at Stony Hazel's building A identified as a Walloon finery?

The Walloon method is generally used in England[11]. The hearth has a pig-hole[1] that was in use until final blow-down of the site.

On the other hand no definite proof exists of the presence of a chafery hearth; and apparently ore was used[1] in the hearth long before 1804.

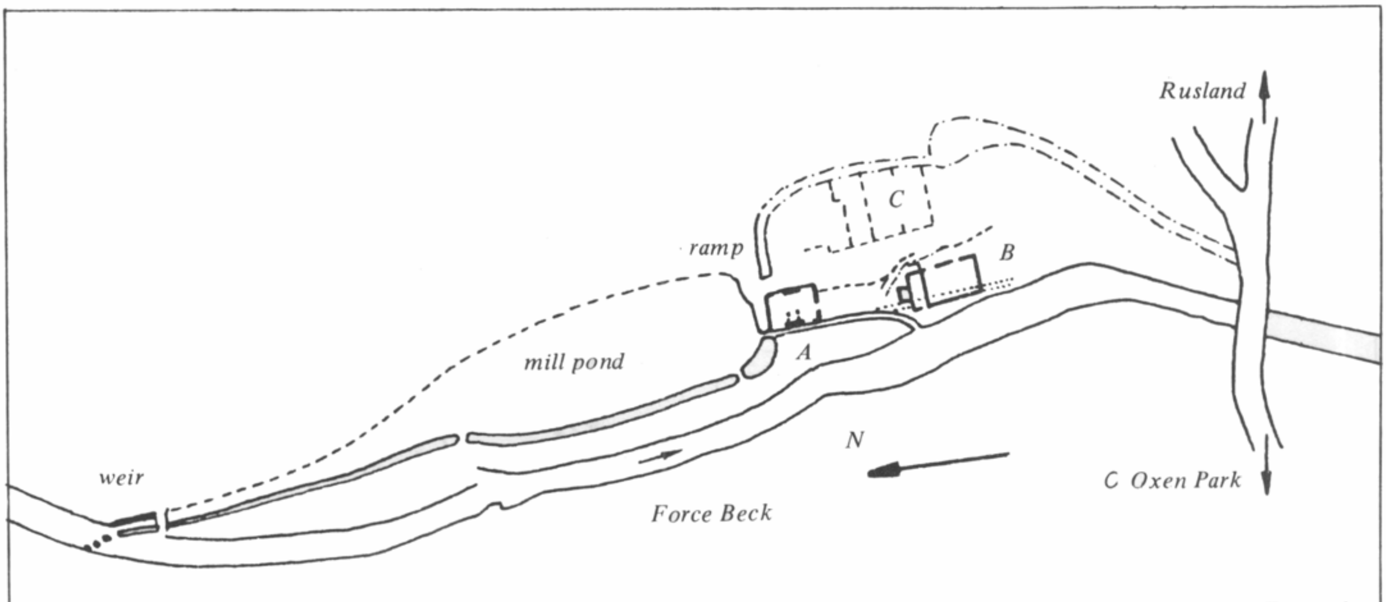
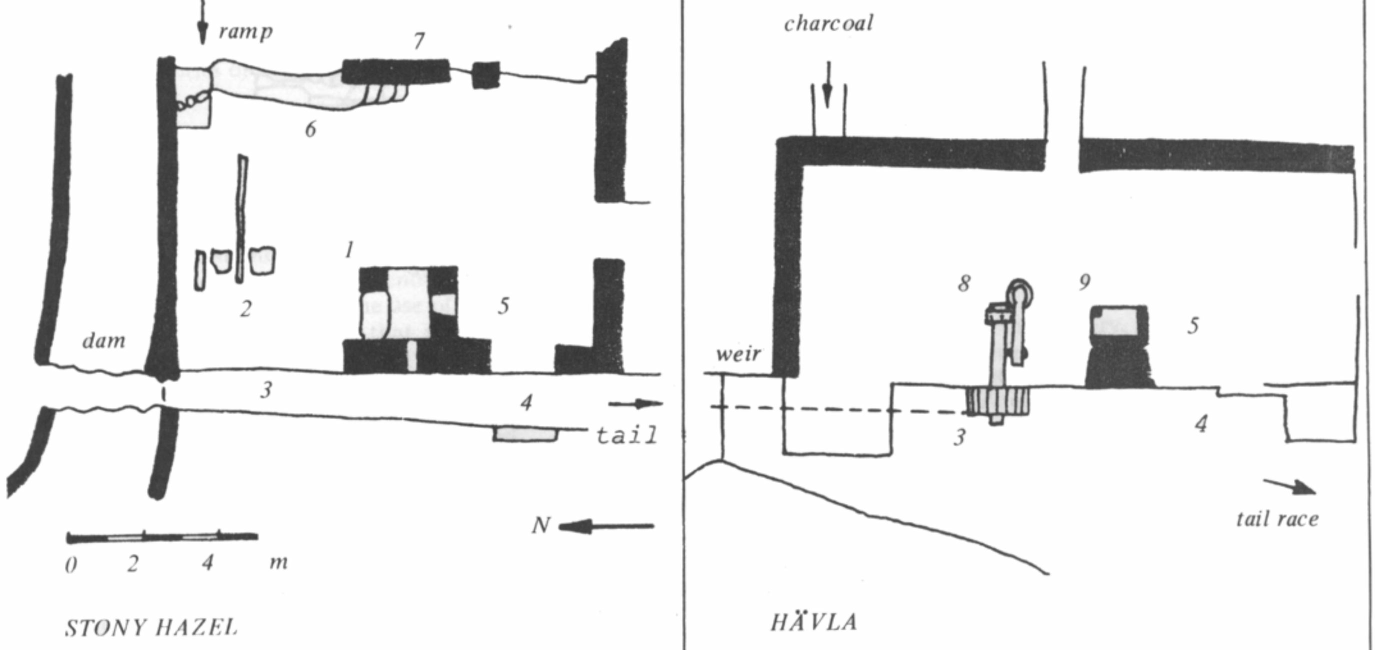


Figure 1



1 hearth
2 remains of hammer
3 hammer wheel
4 bellows wheel
5 position for bellows
6 'natural' staircase
7 buttress
8 belly helve hammer
9 German hearth

NB
Only the oldest parts of the equipment (ca 1800, when the forge used the German method) are drawn here.

Figure 2

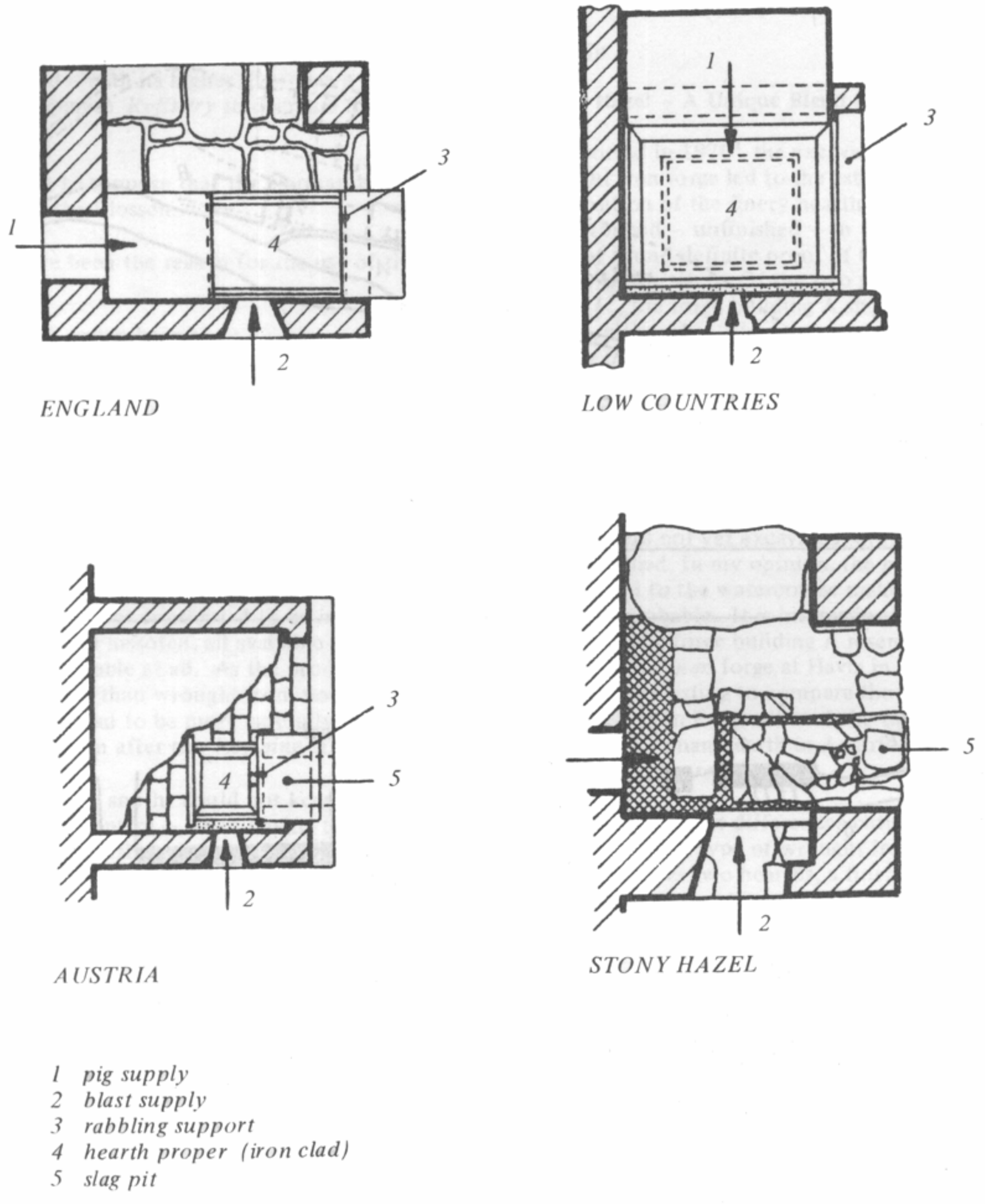


Figure 3

Could it then be that Stony Hazel used a unique English version of the German hearth process by combining the use of a pig-hole with one-hearth technology?

It is well known that many Swedes – knowing the German forge very well as it produced (up to 1840) about 90% of their bar iron – visited the Lake District. The Lake District with its charcoal smelting technique would have offered circumstances quite similar to the Swedish. The advantages of a small German forge are that it uses less charcoal than a Walloon forge (unless the latter uses coal in the chafery); and that it enables smaller production rates and staff.

If we have in Stony Hazel an English German forge, we do have a really unique blending of the Walloon and German forge.

In a reaction to the first version of the above query, Michael Davies-Shiel wrote[2] :

- "The building B was only partially excavated in 1974, when work on the site was stopped (he enclosed a drawing of the details, see *figure 4.*)
- It seems impossible that the main, southern room was a charcoal store, as there was clearly a fireplace and chimney at the northern end of the building.
- The original tailrace of building A is believed to have run straight from A, passing under B and emptying into Force Beck at a minor waterfall South of building B (this course is shown in dotted lines in *figure 1*).

There are three facts supporting this thesis:

- A line of depression along the floor of building B marks the eastern edge of the tail culvert;
- The floor levels of the southern rooms in building B are on a level with normal riverwater in the beck, suggesting that when in use, all the beck water went down the 'below-ground' tail race so keeping the floor there above riverwater level;
- The present '*inefficient race narrows towards the back and is poorly (re) built of mossers*[4].
- The original tailrace might have powered another waterwheel in building B.
- The middle room of building B was clearly lived in (or occupied), but as the hearth bottom in the northern wall is about 0.9 m off the floor, this clearly is not an ordinary hearth.
- The middle room had at least one and the northern room had one window with diamond-paned glass.
- The opening at 0.9m level in the wall between the middle and northern room could (?) be the site for a tuyere, the bellows being placed in the middle room and the chafery hearth in the northern room: but we could not be certain about this when work was stopped in 1974."

Now, in the light of this additional data, let us reconsider the possibilities of building B housing a chafery hearth:

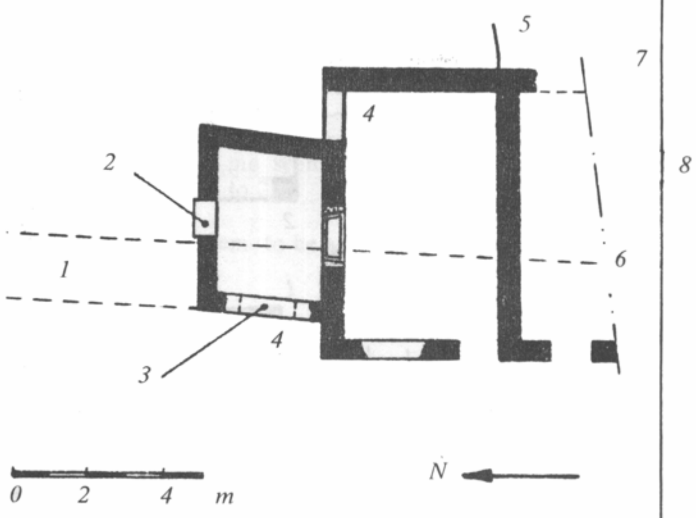
Only one – undershot – waterwheel could have been placed in the building, just behind the doorway into the middle room. This could have powered chafery bellows (sufficient room there), but a separate chafery would also need a hammer and I do not believe that an undershot wheel could be powerful enough to power both hammer and bellows – see the use of two wheels in building A! Apart from that, a hammer powered from the middle room would make for a rather extraordinary lay-out.

The middle room was 'lived in', had glass-paned windows. This is highly unlikely for a wheelhouse.

The northern room measures 2.7 m at 3.6 m (inside) which is too small to accommodate a chafery hearth; it has solid walls, a glass-paned window and a slate covered roof all of which would make work there insufferably hot.

When the finery and chafery hearths are separated, no use is made of the latent heat in the blooms from the finery. This practice might have been necessary when several fineries were combined with one chafery, see e g [12], but it would make the already relatively wasteful use of charcoal in the chafery even more so, in comparison with the German forge method.

My suggestion is, that the main, southern room was the Iron (Store) House, referred to in A Fell's 'Iron Industry of Furness 17-1800'. The middle room would then have been a guard-house, an office and/or a weigh-house (the doorway is about 1.05 m in width); the information available on the northern room is insufficient to determine its use.



1. *hard packed yellow clay*
2. *step stone*
3. *¾post window*
4. *diamond-paned glass*
5. *revetment wall*
6. *eastern edge of depression*
7. *steep bank*
8. *area not excavated*

Figure 4

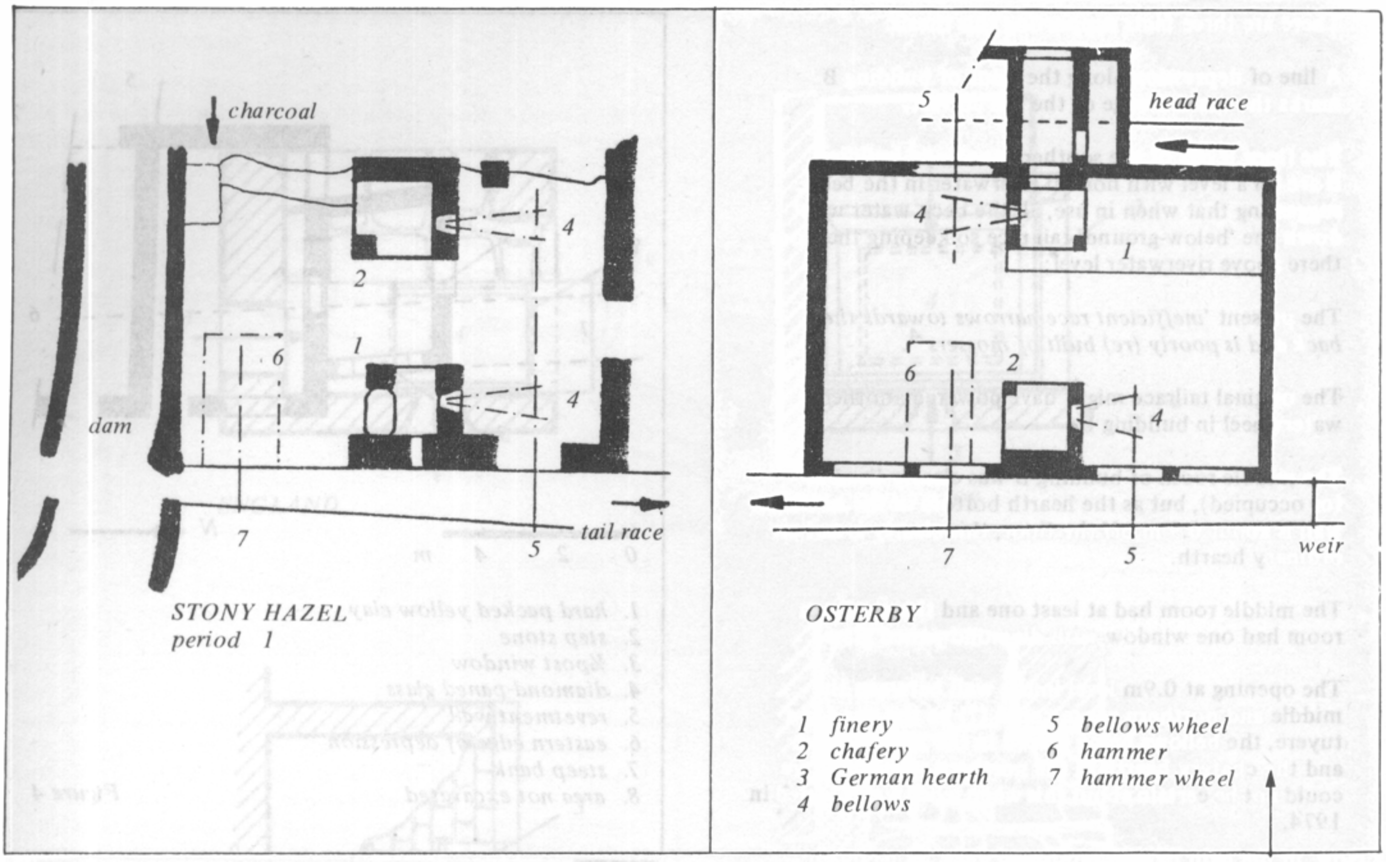
In this hypothesis the building C, shown in dotted lines in *figure 1* on high level ground would be the Charcoal Storage Shed, the transport of charcoal to the Forge Building A taking place on high level via the ramp shown. That building B was situated on top of the tail race seems unavoidable: at its eastern side it is built next to a steep bank, at its western side runs Force Beck.

If building B did not house the chafery, how was the site operated then? My theory is that two distinct periods with separate modes of operation can be distinguished.

In the first period forge building A did house a complete Walloon forge, comprising a finery hearth, a chafery hearth, *one* hammer with waterwheel (midbreast) and a waterwheel for finery *and* chafery bellows (undershot). The suggested lay-out is shown in *figure 5* and it is interesting to compare this with the lay-out of the remaining Walloon forge at Osterby in Sweden, also shown in *figure 5*.

The suggested lay-out explains two rather peculiar aspects of the present remains, ie the heavy buttress into the bank at the eastern wall and the ramp which would be needed for the transport of charcoal into the forge building – the bellows-waterwheel shaft obstructing any other road. Entrance to the forge is by the 'natural' staircase up to the bank.

This first period was then followed by a second in which the forge used one-hearth technology. The former chafery was removed, part of its stones being used in the reconstruction of the southern wall after removal of the long waterwheel shaft; the former Walloon finery was changed into a German type hearth, keeping however its pig-hole at the rear; the under-



Figures 5 and 6

shot waterwheel only powered one set of hearth bellows. See *figure 6*.

As cause for this change-over I suggest:

Insufficient waterpower to operate – by undershot waterwheel – at the same time the finery and the chafery bellows sets.

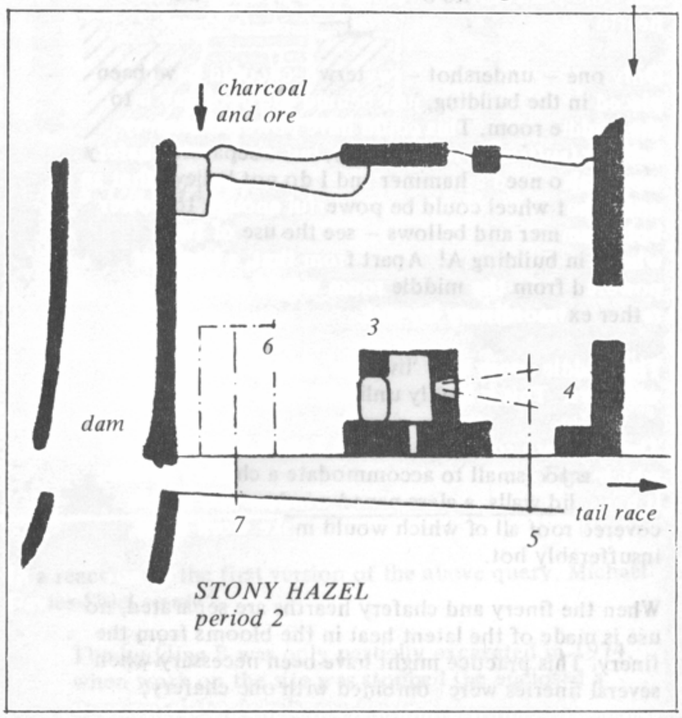
One would expect that the forge's use was inefficient and spasmodic during period 1; and that the change-over would be effected by a management expecting to give the site a new, energetic lease of life.

The pig-hole was kept in use in the new hearth. This causes a unique blend of the German and Walloon methods as described before. There might be a very simple explanation, ie that in the area only 'gueuses' of pig iron were available and no small pigs as needed in the German hearth. It might also have been considered advantageous to wrought iron quality to remove the main disadvantage of the German method: the – unguarded – melting down of pig iron during the first fining stage in combination with the hammering of bars from reheated blooms.

The feeding of pig through the pig-hole would require one extra man at each shift – who would also control the refining stage – in comparison with the German forge method. The chafery hearth of a Walloon forge would require an extra two to three men.

The determination of the type of hearth – German – in period 2 is mainly based on the general lay-out of the hearth (see *figure 3*); and on the use of ore in the hearth, before 1804[13]

The reconstruction of the tail race to its present form



(curved) is in mossers, not fitting the slag pit at the present hearth[2]. These would thus belong to period 1. Presumably the original period 1 tail culvert caved in sometime in the lifetime of the site, somewhere under building B. One would guess that the lower need of power from the undershot waterwheel in period 2 allowed for a less efficient and higher tail race, thus enabling the perhaps quicker or easier reconstruction that can be seen today.

Alex den Ouden

Michael Davies-Shiel has gathered the following facts about the history of the Stony Hazel site[2]:

1718 Built as a bloomsmithy; weir, mill pond and general lay-out date from this time[14]

1726 Re-leasing of the site to a Backbarrow Furnace/ Cunsey Furnace consortium; alteration to a Walloon type forge[14]

1738-44 Cunsey Company Estate Book does not mention the site, it is unknown whether it was worked.

1751 Cunsey Co gives up its lease to Duddon Furnace Co.

1755 The lease reverts to Taylors of Rusland. All this time the Backbarrow Co. retains its half share[15].

1790 The site is worked with 8 men[16].

1822 The Backbarrow Co quits the site and it is taken over by two private persons (the 1781-late 90s manager and the son of the 1745-81 manager).

1825 Estimated date of blow-down of the site.

1833 The site is shown on an estate map as Old Forge not as derelict.

Notes

1 Michael Davies-Shiel; Bull HMG; 1970, 4 (1) 28-32.

2 Michael Davies-Shiel; personal communication.

3 *taken from* the above-mentioned 1970-article (p 28); with some additions from a plan traced 4/11/80 by Michael Davies-Shiel.

4 *quoted from* the above-mentioned 1970-article (p 32).

5 *taken from* H R Schubert: History of the British Iron and Steel Industry; 1957; Appendix 15, p 421 – *as cited in* 9.

6 *taken from* Joseph Wagner; La Sidérurgie Luxembourgeoise; p 52 – *as cited in* a brochure of the Musée du Fer et du Charbon, Liège, Belgium.

7 *taken from* Josef Zeitlinger; Jahrbuch des Vereines für Landeskunde und Heimatpflege im Gau Oberdonau; 91 Band (1944); p 74-5.

8 *taken from* the above-mentioned 1970-article (p 31).

9 George Morton and Joyce Wingrove; Bull BMG; 1971, 5 (1), 24-8.

10 Manfred Wehdorn; Die Baudenkmäler des Eisenhüttenwesens in Osterreich; 1977; p 149.

11 R F Tylecote; History of Metallurgy; 1976; p 87.

12 John van Laun; JHMS; 1979, 13 (2), 55-68.

13 The use of the Franche-Comté method would be another possibility; but this technology is generally dated to a later period than the last quarter of the 18th century.

14 The site clearly was not chosen specifically for a Walloon forge with its higher power requirement than a bloomsmithy.

15 This would to me seem the date of the change-over from period 1 to 2.

16 This would seem to be a rather small staff for a two-hearth forge.

From R E Clough

Dear Sir

I would like to comment on 'Iron Smelting at Isthmia', a paper published by W Rostoker & E R Gebhard in JHMS 15 1981, p41-44.

The paper, with a notable degree of analytical conjuring, claims evidence for 5th century BC iron smelting at The Sanctuary, Isthmia. This is based on slag remains from the site. No furnace remains were found. If we accept that 33% of the sample is redeposited limestone, then the analyses and quantity of slag would suggest that they relate to smithing. Contrary to the authors' opinion, the presence of smithing slags does not necessitate smelting on site, as iron blooms were often traded.

The analytical methods and assumptions are far from satisfactory, and the results difficult to interpret. The high lime could be the result of contamination from the surrounding limestone but in such an environment many of the slag elements such as the alkalis and alkaline earths would weather to carbonates, and hence also be removed in the acid extraction used by the authors. It is possible that the calcium carbonate was part of the original composition eg a lime-iron pigment, which was vitrified during a fire or the calcining process.

The diffraction pattern of the slag was interpreted as magnetite and fayalite. Total iron was not analysed for, but it was assumed to have combined with all the silica present in the form of fayalite. The remaining iron was calculated by difference, to be magnetite, which was confirmed by magnetic separation. The role of alumina and magnesia (4-5%) in the slag structure is overlooked.

While fayalite is a typical mineral constituent of bloomery slags, it is not the only phase in which silica exists, as it is usually combined in a glassy phase containing alumina, calcium, the alkalis and a percentage of the iron. The Isthmia slags were said to be similar to modern blast furnace slags which are glassy. If this is the case then the diffraction pattern is related only to the crystalline phases and is not necessarily representative of the bulk composition. The majority of ancient bloomery slags are crystalline.

Magnetite, in those quantities (29%), is totally uncharacteristic of bloomery slags, which normally consist of fayalite-wustite, and a minor glassy phase. Magnetite is more common in smithing slags, although this is still unusually high. Contrary to the authors' opinion, the furnace requirements for smithing are significantly different from those conditions found in smelting. In the latter, strong reducing conditions are essential, whereas in a smithing furnace, the iron can be forged in oxidising or reducing conditions.

The porosity of the vitrified material suggests that it has never been in a fully fluid state and consequently never (as suggested), run out of the furnace.

Overall, the paper suffers from a poor understanding of the processes behind the production of bloomery iron, and dubious analytical techniques, both of which contribute to misleading conclusions. It is possible that the vitrified material from Isthmia was not related to the iron industry.

R E Clough
Institute of Archaeology, London

Dear Sir,

Smelting or Smithing at Isthmia

Introduction

Rostoker and Gebhard's[1] analysis of slags from a site at Isthmia, dated to the 5th Century BC or earlier, leads them to conclude that they are from an ironworking process rather than copper or lead smelting. On the basis of morphology, chemical and XRD analyses they identified the slag as the product of a bloomery furnace or forging hearth: in their opinion the slag from either process is the same. We believe, however, that the mineralogical composition and texture of slags reflects the processes involved in its production. Work has already been published on this subject[2,3,4] and Sperl[5] has set up a classification of slags based on morphology, microstructure and chemical analysis in which tap slag, furnace bottoms, raked slag, forging slag etc, are clearly differentiated. In our opinion, more information could have been obtained from the Isthmia material. We have attempted below to re-interpret the evidence given by Rostoker and Gebhard on the basis of our own investigations.

Discussion

Assuming that the slag associated with the bloom is not more refractory than that which has drained down to form the furnace bottom (we have no evidence at present to suggest this), Rostoker and Gebhard's premise that smelting and forging slag are the same is in that respect correct. However, conditions are not the same in smelting furnaces and forging hearths. In the former charcoal is burnt in an enclosed space with a controlled air flow to provide both heat and a reducing atmosphere, in the latter fuel is burned on an open hearth to provide heat to make the bloom plastic and allow fluid slag to be expressed by forging and to make the wrought iron workable; the atmosphere is usually oxidising. This difference in conditions and physical treatment is, we find, reflected in the mineralogical composition and texture of these slags.

In the case of tap slag, iron oxide in excess of that required to form fayalite is present as wustite, reflecting the reducing conditions within the furnace, (FeO partially reduced from higher oxides). On tapping, some oxidation to magnetite may occur on the upper surface of a tap slag, although the zone of oxidation generally only extends a few millimetres down into the slag. Furnace bottoms from non-slag-tapping furnaces would tend to be more highly oxidised than tap slags since they have cooled slowly in an atmosphere which, after the completion of the smelting process, would cease to be actively reducing. Such slags would also contain some magnetite. Similarly, the oxidising conditions in the smithing hearth would convert some wustite in the slag to magnetite.

Rastoker and Gebhard's XRD analyses of the Isthmian slag show it to contain magnetite and fayalite, although it should be remembered that glass and phases present in small proportions would not be detected by this method. One of us (J G McD) has investigated the further problem of distinguishing magnetite and wustite by XRD and some details are included as an appendix to this paper.

Rostoker and Gebhard infer from the characteristic plano-convex shape of many of the lumps that the slag had run en masse into a depression and cooled. The further description of the appearance and texture of the lumps agrees closely however, with many smithing hearth bottoms that we have investigated. In these slags the depression in the upper surface is caused not by shrinkage but commonly by the way in which the tuyere blast is directed down into the hearth. The vesicularity results partly from carbon monoxide and carbon dioxide evolution and partly from the process of accretion of the slags. It is unlikely that any gaseous sulphur compound would be significant in vesicle formation.

Conclusion

A fuller description of the plano-convex lumps, eg their dimensions, and details of the other randomly shaped slag lumps would have been useful in determining which processes were carried out on the site. From the limited information supplied, the plano-convex slag lumps under discussion appear to have the characteristics of either smelting furnace bottoms or smithing hearth bottoms. In our experience, the appearance, texture and degree of oxidation described by Rostoker and Gebhard suggest that the latter is the more likely.

S Fells, J G McDonnell and O P Nicholson
Archaeometallurgy Group, Aston University, Birmingham
West Midlands.

Appendix

XRD analysis of ironworking slags

The major mineral constituents of slags are iron oxides and fayalite. The table below lists the 'd' spacings of the three iron oxides[6], wustite, magnetite and hematite for intensities (with respect to the most intense peak), greater than 40%, and the values for fayalite liable to interfere with them. In order that the oxides may be identified (principally wustite and magnetite), magnetic separation of the powdered slag into magnetic and non-magnetic fractions has been used. The non-magnetic fraction consists mainly of fayalite with some wustite, while the magnetic fraction contains magnetite, some wustite and fayalite and any metallic iron inclusions present in the slag. Separation cannot normally be complete but the patterns produced allow the principal oxides present to be positively identified

FeO	Fe_30_4	Fe_20_3	$2FeOSiO_2$
			2.828_{90}
		2.702_{100}	
			2.629_{50}
			2.564_{80}
	2.531_{100}	2.518_{70}	2.500_{100}
2.489_{80}			
			2.191_{50}
2.153_{100}			
		1.696_{46}	
1.522_{70}			1.522_{70}
	1.485_{70}		1.515_{70}
			1.460_{40}

References

1 W Rostoker and E R Gebhard, 'Iron Smelting at Isthmia'. JHMS, Vol 15, No 1, p 41 (1981).

2 G R Morton and J Wingrove, 'Constitution of Bloomery Slags', Part I: Roman, JISI, Vol 207, p 1556, 1969.

3 G R Morton and J Wingrove, 'Constitution of Bloomery Slags', Part II: Medieval, JISI, Vol 210, p 478, 1972.

4 G R Morton and J Wingrove, 'Slag, cinder and bear', JHMS, Vol 3, No 2, p 55 (1969).

5 G Sperl, 'Comparative Studies in Early Iron Slags' Berg and Huttenmannische Monatshefte, 1979, Vol 124, pp 74-84.

6 Powder Diffraction File. Joint Committee on Powder Diffraction Standards.

From Wallace Yater

Dear Sir.

We have a number of people in our Artist Blacksmiths' Association of North America who are doing pattern welded and etched work in iron and steel. I feel that the Wootz process of making crystalline pattern steel could be revived within the limited resources of the studio craftsman, using modern equipment such as electric annealing kilns and high temperature refractories, coupled with a scientific and historical understanding of the material.

In order to make this now well understood process economically practical for the small operator and to avoid repeated frustrating failures in the initial attempts, we are seeking all possible information.

Perhaps someone in the Historical Metallurgy Society may have done some research on this or attempted production and be willing to offer the benefits of some experience to us. So far the only people I have found are Prof Oleg Sherby of Stanford University in California, and Jeffrey Wadsworth of Lockheed Corporation, also in California, who are actually making the stuff, and this is a very fine grain variety designed for space age application. Also Jerzy P Piaskowski of Crakow Poland, has done a most excellent review of the literature, which is in real need of being translated into English.

Anyone willing to volunteer information can contact me

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Wallace Yater

Book reviews

Jennifer Foster, The Iron Age Moulds from Gussage All Saints. *B M Occas Papers No 12, BM 1980, A4, 48 pp + Plates, £2.50. Cheques payable to the Trustees of the BM.*

Gussage is the first site in Britain to show definite evidence for the large scale use of the lost wax process. This evidence resides in the fragments of the moulds found on the site and the tools used for making the wax models for chariot and harness fittings.

Jennifer Foster started her work under Dr Spratling who initiated this study. She has made a detailed examination of the fragments and thereby determined the types and numbers and artifacts produced. Some of these have not yet been found on archaeological sites.

Details resulting from the work include bridle bits designed for pairs of ponies; about 50 sets are represented by the moulds made as part of a single assignment buried in a pit. This was probably a specialist activity set up by itinerant full-time workers. They used selected clays with the deliberate and measured addition of quartz sand for both moulds and crucibles.

Other techniques were employed such as the steel side link dipped in bronze. Separation of adjoining links during casting was assisted by fibre binding.

Understanding of the mould and crucible materials has been assisted by Hilary Howard.

This is clearly one of the first and certainly the most detailed study of a mould assemblage yet made and should be read by anyone interested in the early application of lost wax casting.

R F Tylecote

H G Conrad and B Rothenberg (eds): Antikes Kupfer im Timna-Tal. *(Der Anshnitt, Beiheft 1). 1980, pp 236, 266 illustrations, 12 tables, 34 folding maps and plans. Deutschen Bergbau-Museum, Bochum, Price: 78DM.*

This publication describes the results of continuing research at Timna from 1974 to 1976 conducted by the Deutschen Bergbau-Museum and the Arabah Expedition. It is composed of ten papers by specialist members of the two excavation teams. Separate excavations of the ancient copper mines and a large copper smelting site are reported. The range of related topics includes cartography, geology, mineralogy, geomorphology, mining and metallurgy. The multidisciplinary approach of this new Timna Project presents a foundation for the resolution of many controversies.

In the introductory paper, B Rothenberg reviews the development of archaeological and metallurgical research at Timna and describes the structure of the new Project. Due to the large quantity of mining remains at Timna, a single 4 km^2 model area was selected for intensive analysis. The area was chosen to be representative. The center of the model area is about 2 km away from the excavated smelting site. Together the two excavations permit a complete investigation of copper production.

A total of seven papers deal with the excavation of the copper mines. W Leider reports on the surveying and mapping. Y Bartura, A Hauptmann and G Schone-Warnefeld present the geology and mineralogy of the Timna copper deposit Much of the general information is available elsewhere. There are improved sections and new ore analyses. A most significant study is by A Hauptmann and A Horowitz on the paleomorphology of the model area. Their work identified five erosional terraces. Ancient mine shafts are located only on the older terraces (II-V), with the present Wadi system cutting down and exposing connecting mining galleries. This clarifies many of the odd mine locations in earlier Timna publications.

Two papers, written by H G Conrad, L Fober, A Hauptmann, W Lieder, I Ordentlich and G Weisgerber, describe the copper mines and present an interpretation of mining techniques. The actual excavation of the mines represents a tremendous amount of rather dangerous work. For example, one of the numerous mine shafts (S14) proved to be over 35m deep. The proposed average production value of 30 kg copper from each mine, however, is too low. It was based upon the analysis of disseminated ore remaining in the mines, instead of a quantity estimate of the complex nodules containing considerably more copper. The detailed drafting of the sections and plans of the mines is excellent. It certainly sets a standard for publication of ancient mining systems.

I Ordentlich and B Rothenberg outline chronologically the finds from the excavation of the mines, along with surface finds. There are seven C14 dates on charcoal from four different mines.

In the final paper on the copper mines, B Rothenberg summarizes and proposes a chronology. Briefly, the Early Chalcolithic Elat Culture utilized pits into the alluvial terraces to collect complex copper nodules. If this date is also accepted for Site F2, which is hardly mentioned in the publication, then the Elation Culture could represent the very beginning of copper smelting at Timna. Irregular shafts and galleries cut with stone tools are attributed to the Late Chalcolithic Timna Culture, possibly equivalent to Site 39. The most common regular shafts and galleries cut with metal tools belong to the Late Bronze-Early Iron Age, Egyptian New Kingdom. What were once called 'plates' or ore-dressing locations are actually debris filled mine shafts. No Roman pottery is reported.

A general criticism of the papers on mining concerns the strict division of archaeological evidence between specialist papers. The presentations on mine description and interpretation could have been more usefully combined with the finds and proposed dates. Cross checks between papers is necessary, but difficult. Evidence in one paper is occasionally incomplete in comparison to another paper. There is no index.

Two papers are included on the excavation and technology of Site 30, the large wall-enclosed industrial settlement. Archaeologically, three phases are recognized. The second and most important phase is contemporary with Site 2 and Site 200 (the Timna Temple) and dated during the XIX and XX Dynasties. The pottery is classified as Negev, Midianite, Egyptian and Local. Metallurgically, there are two different extractive processes at Site 30. Stratum II and Stratum III represent the same process for smelting copper, using iron oxide as the flux in relatively small furnaces. Many loci are reported as copper smelting furnaces. However, none of the furnaces were well preserved. This earlier smelting process is in contrast to that of Stratum I, in which manganese flux was used in larger furnaces. The associated remains of copper production, such as melting/refining furnaces, storage pits and anvils, were also found. Site 30 exhibits an advanced level of industrial organization.

The final paper, by H G Bachmann and B Rothenberg, presents the technical interpretation of the metallurgical evidence from Site 30. Two reconstructions are proposed for the smelting furnaces. The small furnaces of Strata II and III are believed to have had an internal diameter of 0.24m and operated with two tuyeres. The larger furnaces of Stratum I, based on reassembly of loosely-fitting lining fragments, supposedly had an internal diameter of 0.54m and six tuyeres. However, due to the lack of evidence, both reconstructions are highly questionable. There are twenty chemical and mineralogical analyses of slag. A single heating experiment was conducted on site using natural draft.

The standard of illustrations and photographs is very good. The folding maps and plans allow a good scale of reproduction, especially for the mining systems. Printing errors are few.

This volume of Der Anschnitt devoted to recent multi-disciplinary research at Timna presents much new information. It is a valuable addition to the study of ancient mining and extractive metallurgy.

John F Merkel

'Glengarnock – A Scottish Open Hearth Steelworks – The Works and the People'

A report on the **Manpower Services Commission Conservation Projects, carried out at Glengarnock, Ayrshire, Scotland, 1979-1980. Editor: Derek Charman. Published by De Archaeologische Pers,Nederland, Lelielaan 3, 5582 GH Aalst, Holland. Price: DFL 16.50 plus postage.**

This is a valuable metallurgical history, unique in so far it has been made possible by the resources of the Manpower Services Commission, and the sponsorship of the British Steel Corporation and the Cunninghame District Council, in association with the Scottish Development Agency.

When the open hearth melting shop of BSC's Glengarnock Works was closed down in 1978, the effect on the local community was profound. For the sake of prosperity, and to better understand the relationship between the Steelworks; and the community it helped create, a Conservation Project was started, the aims of which were to observe, record, and to preserve information still available for later study. To this end, the project consisted of four parts:

1. An oral history project, recording interviews of inhabitants of the community with connections to the steelworks;
2. An archives and records project, processing the surviving records of Glengarnock Steelworks ; preparing references to other, non-company, records containing material related to these steelworks;
3. An archaeological excavation, to investigate possible remains of the c.1840 blast furnaces at the site;
4. A plant conservation project, to work on dismantling and restoring plant of historic interest from BSC's Scottish Works.

The fourth project had to be deferred and the other three ran from August 1979. The first lasted one year; the others six months. Attempts were also made to start a Museum of Steel in the Glengarnock Melting Shop – then standing idle, but still possessing its seven basic open hearth furnaces, whilst in 1978, the Scottish IA Survey had published plans for a Museum of Steel, in a similar manner to the Ironbridge Gorge Museum. In mid-1979, a feasibility study of new – more restricted – plans was made. These failed in the end on financial problems. Meanwhile BSC and the local authorities indicated unwillingness to commit themselves further.

The Historical Metallurgy Society, involved as a supporter of the Museum of Steel project, decided to redirect its efforts towards a wider aim; international documentation of the remains of the bulk steel industry.

In this book, the set-up, organisation and development of the Conservation Projects are described, and a survey is given of the results achieved, plus an indication of the material made safe and accessible for further researches. The concept of a Museum of Steel and the subsequent project for International Documentation are also set out.

The editor, Derek Charman, became BSC Archivist – later designated Co-ordinator, Records Services – in 1970. The policy of conservation adhered to until recently by BSC was instigated by him in 1973. In his official capacity, Mr Charman formulated – in co-operation with several other officials – the original concept of the Conservation Projects. He became Chairman of the Steering Committee for these Projects and was thus intimately involved in their development. The Museum of Steel feasibility study was commissioned by BSC's Records Services and the Scottish Development Agency, and briefed by Mr Charman. He thus followed the evolution of the plans for the intended museum to their conclusion.

This is a record of the three-part Conservation Project and it is extremely worthwhile.. While the recording project and the archaeological excavation might be said to be traditional processes, the oral history project is an example of new methodology. It is the tape-recording, of the voices of those actually involved in the operation of the works. It required expertise for which the interviewers were especially trained, and with the competence of the operators and the co-operation of the local population has produced a unique record of the steel making era of Glengarnock.

After the collapse of the associated Project to create a Museum of Steel the enthusiasm was diverted towards stimulating interest in 'recording the history of bulk steel-making while there is still time'. The outcome is awaited.

The book has 120 pages and 7 photographs, mainly of the early blast furnaces, with 15 line drawings by Alex den Ouden. It is excellent value and highly recommended.

C R Blick

The Electrum Coinage of Phocaea and Mytilene
Friedrich Bodenstedt, ISBN 3 8030 10292
(Die Elektronmunzen Von Phokia und Mytilene)
Verlag Ernst Wasmuth, Tubingen 1981, 390pp, 3 colour and 67 black and white plates, 4 maps, 74 tables. Index and bibliography. Hardback, 21 x 29.7 cm format with colour photographs of electrum coins on the dust cover. Price 95 DM.

The rich and beautiful series of electrum coinage (hektai) minted from the late 7th – 4th century BC by the Eastern Aegean Greek towns of Mytilene, Phocaea and Cyzicus have been the subject of intensive research for the past twenty-five years. Not only are the coins amongst the earliest known but also the unique composition of the coin metal makes them even more interesting. The last decade in particular has seen a great expansion of numismatic studies of this coinage complemented by the application of various methods of chemical and metallurgical investigation.

The new book by Bodenstedt in many ways presents the extension of his work on the Phocaean electrum coinage published five years ago ('Phokaisches Elektron Geld von 600-326 v.Chr.', Mainz 1976) and in fact the earlier book remains a necessary reference for a reader interested in the metallurgical and analytical problems concerning ancient electrum coinage.

'Die Elektronmunzen . . .' contains the results of an immense numismatic study of 2866 hektai from 34 museums, 17 private collections and numerous coin dealers. An extremely detailed catalogue of the coins forms more than a third of the book. The hektai are divided into major chronological groups based on the composition of the alloy. Bodenstedt distinguishes three alloying periods for Phocaea and two for Mytilene. The alloying periods have been established on the basis of neutron activation analyses supplemented by specific gravity determinations of 162 hektai reported in the 'Phokaisches Elektron Geld . . .' The average gold content for Phocaean hektai changes from 55.5% in 600-522 BC to 40.5% in 477-326 BC. For Mytilene (where the hektai were not minted before 521 BC) the change is from 43.9% in 521-478 BC to 40.3% in 357-326 BC. However, the standard deviation of gold content in particular groups is very large and makes one wonder if the results do not represent a steady decline in gold content rather than well-defined alloying periods. There is archaeological evidence from Sardis that the Lydians were able to separate gold by salt cementation by the mid-sixth century BC. This fact does not prove however that cementation was necessarily used for the production of coin metal for the issues of Phocaea and Mytilene. The lead content of 0.2-0.3% detected in 4 coins analysed by the 'wet' chemical method is not, as claimed by Bodenstedt, a proof of the use of cementation; it can instead be the result of alloying with copper (each of these coins contained above 12% Cu, and ancient copper always contains some lead) or of using silver from galena to debase the alloy. Moreover Notton's experiments (Gold Bulletin 7 (1974) 2, 50-56) on salt cementation show conclusively that the addition of lead severely hinders the purification of the gold, and that the assertion of Diodorus, reporting Agatharchides, that lead was a necessary ingredient must be mistaken; possibly Agatharchides was deliberately misled to preserve the secrecy of the process. Significantly, in the II and III alloying periods when the gold content declines from c.46% to c.39% the copper rises from 10% to 12%, but also silver increases from 44% to 49%. (Obviously a slight increase in copper and silver content simultaneously would have less influence on the colour of the alloy, than if only copper was used). There are at least two ways of achieving this debasement: either 1) cementation parting of gold from native gold (native gold always contains silver and a little copper) followed by alloying with known proportions of silver and copper, or 2) alloying of native gold with silver (scrap?) and copper. Which method has been used by the ancient Greeks?

The present state of research on Greek white gold still does not provide a certain answer to this question. As J F Healy put it in his excellent review of the problem ('Greek white gold and electrum coin series', Metallurgy in Numismatics I, 1980, 194-215): 'But in spite of the continuing attempts to correct the data available, some of the old persistent doubts remain, even among the most enlightened, about the real goals at which the Greeks were aiming in their manufacture of the ternary electrum alloy'. If their aim was the production of an electrum alloy of controlled composition, then they would necessarily have been forced to produce pure gold by cementation, then adding controlled amounts of silver and copper. The analyses, however, show that in each alloying period and for each mint the composition was not very closely controlled. The new book by Bodenstedt provides also a new discussion of the earlier results bearing on the influence of voids resulting from casting blanks on the SG measurements, frequency tables of SG for particular groups of coins and new SG results for about 500 coins.

There is also a chapter describing exactly the minting technique and the production of dies and blanks. Another chapter deals with forgeries and a statistical evaluation. Unfortunately there is no study of the techniques used by forgers.

The author gives a very good historical and numismatic background supplemented by maps, colour photographs of the region and stylistic comparisons between architecture and the art of the coin dies.

The book is very well printed and the photographs of the coins are of excellent quality. Together with the author's previous book on the Phocaean coinage they form the most thorough study available of the Greek electrum coinage with an admirable effort to extract as much technical and technological information about them as possible.

Zofia Stos-Gale

'LES FORGES DU SAINT-MAURICE': Their historiography' Louise Trotter. 'History and Archaeology, No 42'.
Published by National Historic Parks and Sites Branch, Parks Canada, and obtainable from Canadian Government Publishing Centre, Supply & Services Canada, Hull, Quebec, Canada K1A OS9: $11.00 in Canada; $13.20 outside

This is the story of the first ironworks in Canada, which commenced operations in 1730 and closed down in 1883. It is not the first ironworks in the North American continent, where there are known C17 blast furnaces in Virginia, Massachusetts and New Jersey.

The works was established on the Saint Maurice river, a tributary on the left bank of the Saint Lawrence, near bog iron ore deposits, in the centre of the Province of Quebec. The hinterland of the Saint Maurice area was vast, some 24,000 sq miles, but development of the territory was taking place and the establishment of the works was the result of insistent pressures on the mother country (France), since 1660, for concessions in regard to the mining of iron ore in New France.

Aware of the import of this event in a developing country, several historians have concentrated on recording the development of the ironworks. Some twenty papers have been written but the subject proved popular with other disciplines and some two hundred papers have been located and studied – monographs, brochures, dictionaries, articles – in which were found descriptions and analyses from the viewpoints of both pure and applied sciences like biology, geology, metallurgy and technology, and of social sciences like economics, ethnology and sociology. From this study, major themes concerning the industry of Les Forges were identified. So this historiography – this summary of works written – is set out in three parts.

The first part deals with the Saint Maurice area from the viewpoint of physical, industrial and human environment. The second part deals specifically with Les Forges and the third part is a comparative study, in which typical examples of ironworks in France, Great Britain and the United States are cited for comparison between them and Les Forges. In this way, it is said, it was possible to measure the influence of other undertakings, and especially the impact of scientific discoveries on Les Forges.

Most of the studies, again it is said, are traditional, so there might be other approaches in order to do full justice to the works for is not history a study of changes? That is if you do not accept that history repeats itself or 'plus ca change, plus c'est la meme chose'. Certainly new approaches and methodology – archaeological excavation and oral recollections – are now being adopted so the way is open to modern historians to strive to sort out the truth of the rise and fall of Les Forges.

This publication is well produced, and the translation from the French is good – except for one small error, noted by this reader, where the process 'rolling' has been translated as 'lamination' – a steel defect which causes extreme consternation!

The bibliography is extensive, while the illustrations are valuable. There are three original maps and plans of the area, six pictures of the plant from 1842 to 1900, three of the blast furnace as it disintegrated, four of products – cast iron stoves and pots made at the works and three of current excavations being conducted by Parks Canada. The standard of preservation and conservation achieved is impressive.

Louise Trotter thinks that the history of Les Forges Du Saint Maurice is still waiting to be written. She, and Parks Canada, have certainly produced an excellent, extensive base from which this can be attempted.

C R Blick

Abstracts

General

H Knoll et al: Pliny the Elder on iron.
Bericht Nr 81 des Geschichtsausschusses des VDEh.
Archiv fur das Eisenhuttenwesen 51, 1980, **12**, *487-492 (In German).*

A new concept of interpreting the compilation of Pliny's text and a new translation of books XXXIX, XL, XLIII-XLVI of the Natural History, dealing with iron. The translation is commented on from different points of view: philological, archaeological and technological. CPSA

G Michler, K Simon, F Wilhelm and C Steinberg: Vertical distribution of metals in a sediment core of a subalpine lake indicating stages in the development of civilization.
Arch Hydrobiol, 1980, **88**, *No 1, pp 24-44. In German.*

Variation in metal content at different levels of a 382 cm sediment core from a Bavarian lake can be correlated with different man-induced influences over the centuries, such as deforestation of surrounding areas, the introduction of coal mining, the development of industry, and several recent factors (the expansion of motor traffic, use of salt on roads, pollution from municipal sewage, and use of artificial fertilizers). Metals determined were Cd, Pb, Cu, Zn, Mn, Fe, Ni, Cr, Ca and Mg (by atomic absorption spectrometry) and Na and K (by flame photometry). AATA

W A Oddy: Swaged wire from the Bronze Age?
MASCA Journal, 1980, **1**, *No 4, pp 110-111.*

A brief account of two artifacts on which gold wire with a semi-circular cross-section has been used. The only way that semi-circular wire could be made is using a swage block, and this seems to be the earliest recorded use of a swage. AATA

W A Oddy: Symposium on the history of technology of the precious metals.
Gold Bull, 1980, **13**, *159.*

Brief report of the Ludwigsburg symposium which had included papers on present-day panning for gold in the Alps, on (almost) non-destructive sampling of Celtic moulds for gold coin-blanks, on the polarographic detection of alloy changes in gold bracteates, and on soldering and filigree. BAA

S Odell and M Goodway: Harpsichord wire of the 17th and 18th Centuries.
AIC Preprints, San Francisco, California, May 1980, pp 62-71.

A history of harpsichord wire including its mechanical composition and metallurgical characteristics. AATA

I G Polmear: Steel — an historical perspective.
Metals Australia, 1980, **12**, *No 4, pp 6-10.*

The history of steelmaking from the beginning of iron smelting by Hittites around 3400 years ago is discussed. Steel was used both for weapons and domestic applications; and techniques were improved by succeeding civilizations, ie the forging of composite sword blades in Egypt, the invention of the blast furnace in the fourteenth century. The Industrial Revolution in Great Britain saw the introduction of modern steelmaking practices by Huntsman, Cort and Bessemer. A description of current techniques and uses of steel is included. AATA

P Sillitoe: Stone versus steel.
Mankind, 1979, **12**, *151-61.*

Describes experiments to compare the relative efficiencies of stone and steel tools among the Wole of Papua New Guinea, who still remembered the use of stone. Various experiments were done and the results tabulated in different ways and discussed. The crude figure which emerges, that steel tools are 1:4 times faster than stone, needs to be seen in the context of how work is actually done in a Stone Age society. Comparisons with experiments elsewhere are drawn. BAA

H Yabuki and M Shima: Akaganeite as an oxidized product of iron implements from the vestiges of ancient age.
Sci Pap Inst Phys Chem Res (Japan), 1979, **73**, *No 4, pp 71-77. In English.*

Naturally occurring akaganeite (I) was analyzed and compared to synthetic β-FeOOH. The I occurred with magnetite, goethite, and lepidocrocite as oxidation products in ancient iron implements. Tests conducted included x-ray analysis, Moessbauer spectral analysis, electron probe x-ray micro-analysis and thermal analysis. The I contained 3.5 wt.% Cl. Some Cl and F is necessary for formation of the β-FeOOH crystal structure. The Cl was derived from salt buried with the iron implements. AATA

British Isles

C S Cattell: The 1574 lists of Wealden ironworks.
Sussex Archaeol Collect, 1979, **117**, *161-71 refs.*

Discusses the problems of interpreting the seven separate lists which relate to the extent of the Wealden industry in 1574. BAA

J Close-Brooks and J M Coles: Tinned axes.
Antiquity, 1980, 54, 228-9.

Draws attention to several Scottish axes, halberds, and daggers with tin-rich surfaces, giving a silvery appearance. BAA

A Lawson: A Late Bronze Age hoard from Beeston Regis, Norfolk.
Antiquity, 1980, **54**, *217-9.*

The hoard contained 21 items, mostly looped socketed axes of different types, but also one valve of a bronze mould. Date: 9th/8th century BC. BAA

H McKerrell: The use of tin-bronze in Britain and the comparative relationship with the Near East. *In book. In: The Search for Ancient Tin, edited by A D Franklin, J S Olin and T A Wertime, 1978, pp 7-24.*

Archaeological tin-bronze artifacts of about 2000 BC of Britain were studied and compared with those from other parts of Europe and the Near East. AATA

K Muckelroy: Two Bronze Age cargoes in British waters.
Antiquity, 1980, **54**, *100-9.*

Two finds of bronzes from presumed wreck sites have considerable implications for understanding BA metal distribution frameworks, cross-Channel links and shipping organization. The 190 bronzes from Langdon Bay near

Dover are interpreted as a cargo of scrap, originally artefacts from several distinct areas of France. Seven bronzes from Moor Sand, Salcombe date to the Middle/ Late Bronze period in France, and may also originate in a wreck. AATA

H N Savory: Guide-catalogue of the Bronze Age collections.
Cardiff Nat Mus Wales, 1980, Price £7.50 +£1.32 postage.

The catalogue has an introduction giving traditional divisions of the Bronze Age and their main characteristics. An appendix by J P Northover records results of 550 analyses and traces the evolution of alloys. AATA

J S Jackson: Bronze Age copper mining in Counties Cork and Kerry, Ireland.
Scientific Studies in early mining and extractive metallurgy (ed P T Craddock) (= Brit Mus Occas Pap, 1980, **20***) 9-30.*

Discusses 74 mines assigned to EBA on the basis of their concealment by peat growth. Estimates of the tonnage of ore recovered are made and converted to an estimate of tonnes of finished copper metal. It is suggested that Ireland was able to export copper during EBA. BAA

C F Tebbutt: The excavation of three Roman bloomery furnaces at Hartfield, Sussex.
Sussex Archaeol Collect, 1979, **117***, 47-56.*

TQ 452309. Insufficient superstructure remained for any of the furnaces to be assigned to dome or shaft types, but each was accompanied by a reheating hearth. An anvil site was also identified. BAA

Europe

P Angel, L Mihok and S Siska: Some applications of analyses of ancient iron and slags.
Hutnicke listy, 1980, **35***/9, 655-658 (In Czech).*

Early La Tène period bloomery slags from Cecejovce, E Slovakia, were investigated. They are mainly wustitic/ fayalitic, although in some of the captions wustite is confused with magnetite. A lump of pearlitic steel was also examined. These finds represent the earliest analyzed bloomery waste from Slovakia. CPSA

F Boersig: Calking irons of Bremen Hanseatic cock-boats from the end of the 14th century.
Stahl Eisen, 1980, **100***, No 5 ,pp 224-226. In German.*

Calking irons discovered in the wreckage of a 14th century ship were analyzed with regard to their metallurgical structure, hardness and composition. Quantitative analysis of various elements in the objects can aid in ascertaining the source for the iron, which strengthened the ship and prolonged its stability. AATA

J Butler: A Late Bronze Age drawing instrument?
Palaeohistoria, 1979, **21***, 195-203.*

Compass-drawn decoration is common in LBA ornamental metalwork, but no suitable instrument has previously been identified. A bronze rod from Drouwens with 17 cylindrical perforations and a handle could have been used as a rather crude mechanical aid for drawing circles and concentric circle patterns: spacing suggests the intention to produce regular 4.4mm intervals. Several parallels and near-parallels are cited. BAA

C Craine: The examination and treatment of a 6th century silver openwork lamp from the Byzantine Church of the Holy Sion.
AIC Preprints, San Francisco, California, May 1980, pp 9-19.

Treatment of a medieval silver object which was crushed and fragmented. Discusses condition before treatment, method and materials of fabrication, problems of conservation and the treatment carried out which included cleaning, annealing and assembly. AATA

C J Eiseman: Greek lead: ingots from a shipwreck raise questions about metal trade in Classical times.
Expedition, Winter 1980, **22***, No 2, pp 41-47.*

A shipwreck from around 400 BC found near Porticello in southern Italy has been excavated to yield several items of lead, including two lead ingots. Isotopic analysis of these leads indicates that all but one originated from Laurion, in Greece. The significance of these findings is discussed. AATA

I Glodariu: Metallurgical-workshops of the Dacian Sarmizegetusa.
Actes du II^{e} Congres international de thracologie II. Bucuresti 1980, 82-91. (In French)

There were numerous smithies situated on terraces in the Dalul Gradisti suburb of the royal capital of Sarmizegetusa. They were located in rectangular houses in which iron bars, objects, blooms, blacksmith's tools, and tuyere nozzles were found. Dating: 2nd half of the 1st century AD. CPSA

Z Hegedus: Manufacture of cast iron tablets and study of the grave tablet of 1598 from Selmecbanya.
Banyasz. Kohasz. Lapok, Oh tode, 1979, **30***, No 10, pp 235-239. In Hung.*

The composition and microstructure of an iron grave tablet from 1598 are given. No clues could be established concerning the origin of this tablet. The state of the art of iron casting in the 16th century is discussed. AATA

Z Hensel: Metallographic investigations of iron objects from Tuste, province of Warsaw, site 1.
Sprawozdania Archeologiczne, 1979, **31***, 129-139. (In Polish).*

Artifacts from the hoard published in the paper by A Walus were made of wrought iron without any attempt at improving their properties. Phosphorus content below 0.15%. CPSA

K Horedt: Moresti — Excavation of a pre-historic and early settlement in Siebenburgen, Roumainia.
Bucuresti 1979. In German.

Blacksmiths' tongs and an eyed chisel were found together with slags, dating from the 6th century AD. One of the knives was examined metallographically, revealing that it was a tempered medium-carbon steel. This knife belongs to a period later than the 6th century. CPSA

B Jovanovic: The origins of copper mining in Europe.
Scientific American, May 1980, **242***, No 51, pp 152-167.*

The earliest known copper mines in Europe have been found at Rudna Glava, Yugoslavia, and date from the late Neolithic Vinca culture. Pottery vessels (used to carry water in the heating and cooling mining process) and antler tools found in the vertical shafts are described and illustrated. AATA

B Klima: Production of Slavic blacksmiths and its historical importance.
IV, Medzinarodny kongres slovanskej arcgeologie, Sept 1980, 15-22. Sbornik referatu CSSR, Nitra 1980, 76-83.

The article draws attention to less well-known groups of the blacksmith's work such as mountings and fittings: keys, locks, nails, clamps and structural iron. On the basis of materials excavated from important sites the work of the locksmith can be identified from the 9th century AD in the Slav world. CPSA

B Klima: Slav locksmith's work as illustrated by the finds from Mikulcice. *Studie Archeologickeho ustavu CSAV v Brne, vol VIII/3. Praha. 107pp, 43 figs (In Czech).*

Excavations of the great 9th century centre of Mikulcice, Moravia produced a quantity of iron objects. Types of iron keys, locks and lock-fittings, as well as various clamps, are discussed. CPSA

J Kocich and M Leukanicova: Metallographic examination of the Nizna Mysla sickles .
Slovenska archeologia, 1980, 28/2, 395-400. (In Czech, German Summary).

The metallographic investigation of a hoard of three iron sickles of different types is reported. One is made of hardened carbon steel, another one is piled together from low-carbon bands, and the third has a wrought iron core and steel shell (quenched). CPSA

R Kutschej: The cast slag cannon balls of Duke Julius of Braunschweig.
Erzmetal, 1979, 32, No 11, pp 488-491. In German.

Several 16th century cannon balls were analyzed and shown to contain large amounts of Fe, Zn, Ba and S (27, 15, 11 and 10% respectively). These cannon balls were prepared from slags of Pb smelters, and the unusually high content of Ba was naturally and unintentionally introduced from Ba-rich smelter slags. The principal phases within the cannon ball were recognised by light microscopy, microprobe analysis, and x-ray diffraction analysis as Zn sulfides, Fe oxides and spinels and silicates of Ba, Ca, Mg and Al. The poor healing of wounds produced by these cannon balls may have been due to toxic effects of the Ba, Zn and S. AATA

K Lamm and Z Lupostron: Stockholm, Kungl Vitterhets Excavations at Helgo V: 1 Workshop; Part II. Hist Antik Akad/Almqvist & Wiksell, 1978.

The contributors to this volume on the Late Iron Age objects from Helgo treat the locks and keys, workshop tools, iron currency bars, rod-shaped blanks, and metallography. BAA

J P le Bihan and P Galliou: A group of bloomery furnaces discovered near Quimper, Brittany.
Bulletin de la Societé Archéologique de Finistere, 1974, **102**,*17-46 (In French).*

Stone lined bases of large furnaces with iron slag were found at Kermoisan, near the oppidum of Kerkardec (diameters about 90 cms). Dating: ca 1st century BC/ 1st century AD. Flat hearths. CPSA

F Ovari and E Gegus: The role of minor elements in the characterization of third century Roman coins.
Hung J Ind Chem, 8, *1980, No 1, pp 35-44.*

AATA

A Pawlowski: A concentration of smelting furnaces and iron metallurgical tools of the Roman period on site B at Dobrzen Maly, commune of Dobrzen Wielki, province of Opole.
Sprawozdania Archeologiczne, 1979, **31**, *193-204. (In Polish).*

The area excavated produced 5 bloomery furnaces with slag pits (induced draught from multiple tuyeres is presumed). There were also stocks of roasted ore, 20 reheating hearths. The weight of slag blocks from the furnace hearths was 65-120 kgs. Three iron picks were found. Dating: Roman period C. CPSA

J Piaskowski: Metallographical investigations of ancient iron objects from Kietrz and Sulkow ,Opole.
Silesia Antiqua, 1979, **21**, *69-79. (In Polish, French summary).*

A hard steel La Tène sword was found in a grave and wrought iron knives from a settlement site; together with iron slags with high phosphorus content. CPSA

J Piaskowski and Z Hensel: Metallographic investigations of iron objects from a cremation cemetery at Brzeze near Bialobrzegi, province of Radom.
Sprawozdania Archeologiczne, 1979, **31**, *141-150. (Polish, English summary).*

Analyses of a sword (heterogeneous steel), two knives (wrought iron, one with high nickel content of 0.345%), a sickle (heterogeneous steel), and two wrought iron fibulae (tinned?) of the Late La Tène period. CPSA

H Presslinger, C Eibner, G Walach and G Sperl: Results from research work in the area of urnfield age copper metallurgy in the Paltental valley.
BHM, Berg-Huettenmaenn, Monatsh, 1980, **125**, *No 3, pp 131-142. (In German).*

Included are discussions of the use of magnetometers to locate the smelter and slag sites, the excavation of such sites, reconstruction of vessels from isolated fragments, and chemical analysis of the recovered metals. AATA

A Walus: Summary: A set of smith's and farming tools of the Roman period site 1 at Tluste Commune of Grodzisk Kazowiecki.
Sprawozdania Archeologiczne, 1979, **13**, *118-128. (Polish, English summary).*

Thirty bloomery furnaces and many 'smithing' hearths were found on the Roman site. An iron hoard consisting of 7 objects, comprising blacksmith's tongs, a sledgehammer, a horned anvil, and coulter, a ploughshare, and two intrusive smaller hammers were found. CPSA

W Rozanski and I Slomska: The suitability of charcoal mixtures for iron smelting charges from the Holy-Cross-Mountains bloomery furnaces as to their reactivity.
Kwartalnik Historii Nauki i Techniki, 1980, 25/2, 379-386. (In Polish).

Impressions of both coniferous and deciduous charcoal in slag blocks from the Holy Cross Mountains furnaces inspired an interesting research project based on tests with charcoal mixtures. At temperatures under 600^{o}C pine charcoal is the most reactive material, whilst at $800\text{-}1000^{o}$C beach charcoal and its mixtures with coniferous charcoal is richest in CO. The mineral components of the charcoal may also have a strong influence on the reactivity of the charge: Ca0, Fe0, $K_{2}0$ etc act as catalysts. CPSA

J Riederer: Metal analysis of bronzes from Sardinia. In Catalogue.
Kunst Sardiniens (J Thimme, Editor), Badisches Landesmuseum, Karlsruhe, Germany, 1980, pp 156-160. (In German).

Metal from 64 bronze objects from Sardinia, the Nuragic period (6th-8th century BC) was analyzed by means of atomic absorption spectrography. AATA

K Romanow: Results of excavations in the Old Town at Wroclaw, site I.
Silesia Antiqua, 1978, 20, 196-216. (In Polish, German summary).

The paper is entirely devoted to iron working as revealed on the site. The frequency of finds indicates that the most intensive smithing activity took place in the second half of the 13th century AD, although there is evidence of smithing from the 12th to the 14th century. A number of blanks and many knives with welded steel blades were found. No metallographic analyses. Problems of technology are discussed but only in broad outline. CPSA

J R Weinstein: Preliminary analyses of copper, bronze and silver artifacts from Lapithos, Cyprus.
MASCA Journal, June 1980, 1, No 4, pp 106-109.

Twelve copper or bronze objects and one silver object dating from 2300-1600 BC (Early Cypriot I to Middle Cypriot III) were examined via metallographic sections and by qualitative element identifications in the scanning electron microscope. Several daggers and a sword had been alternately annealed and hammered, and left in a lightly cold-worked state. Another dagger was in a heavily cold-worked state, and various toggle pins were found to show no working after annealing. A silver ring contained traces of iron and chloride, and particles containing copper, but did not contain lead; the silver was possibly extracted from an ore containing copper. AATA

I R Selimkhanov: Ancient tin objects of the Caucasus and the results of their analyses.
In book, The Search for Ancient Tin, edited by A Franklin, S J Olin and T Wertime, 1978 ,pp 53-58. In English.

The composition of ancient tin objects of the Caucasus are given. AATA

R F Tylecote: Early tin ingots and tinstone from western Europe and the Mediterranean.
In book, The Search for Ancient Tin, edited by A D Franklin, J S Olin and T A Wertime, 1978 pp 49-52. In English.

An archaeological study is given of sources of tin ingots and cassiterite in western Europe and the Mediterranean. AATA

V Souchopova: Great Moravian iron production in the Central part of the Moravian Karst.
Zkoumani vyrobnich objektu a technologii archeologickymi metodami. Buno 1980, 120-127. (In Czech).

The paper deals with recent discoveries of bloomery workshops from the 8th-9th centuries AD. It appeared in a volume entitled 'Investigations of production plants and technologies by archaeology', the proceedings of a specialized conference held in 1979. Other papers dealing with early iron technology in the same volume: V Souchopova: Experimentalni tavby v rekonstrukcich slovanskych peci (Experimental smelting in reconstructed Slav bloomery furnaces), 128-133; short description of trials carried out in the early 1970s and in 1978. J Merta and K Saransky: Nalez strukove hroudy z Obranskeho/hradu. (A slaggy lump from the castle of Obrany, Moravia), 134-136. Presumably a slag block from a forge; hematite, wustite and magnetite identified by X-ray diffraction. CPSA

S Teodor (Mrs) and P Sadurschi: Archaeological finds from Lozna, Dersca village, district of Botosani.
Hierasus Annuar 78, 921-130. (In Polish, German summary).

Among La Tène C-D finds there is a description of the well known iron hoard, consisting of 54 objects. CPSA

B A Khorev: Excavations of the Ananevka Hill-fort, Far Eastern Russia.
In: Archeologiceskiye otkrytiya 1979 goda. Moskva 1980, 238-239. (In Russian).

An interesting iron vice with two pivoted arms and a wedge, for working small artifacts. 12th-13th cent AD. CPSA

E Tomczek: Results of rescue excavations at Dobrzen Malyn, province of Opole, site B.
Sprawozdania Archeologiczne, 1980, 31, 167-191. (In Polish).

This paper describes iron production at this Romano-Barbarian site of the Przeworsk culture. In addition to large slag-pit furnaces, charcoal heaps, and other auxiliary installation, the base of a large bloomery furnace was discovered, which was interpreted as a domed furnace of 134 cms diameter. CPSA

Asia

G J Fabris and F E Treloar: x-ray fluorescence and atomic absorption analysis of Sarawak gold artifacts.
Archaeometry, 1980, 22, No 1, pp 93-98.

Provenance studies were made on gold artifacts from sites in the Sarawak River Delta. X-ray fluorescence and atomic absorption analysis methods were utilized. AATA

J Piaskowski: Examination of two Damascus Steel (Bulata) blades.
Wiadomosci Hutnieze, 1981, Marzec, Nr 3, Rok xxxvii, Set 81-116. (In Polish).

Samples were obtained from two rare artefacts, an Arabian sword and a Persian dagger, and submitted to chemical, metallographic and X-ray examination – 19 illustrations, 3 tables. Whereas both samples indicated 1.5%C, the phosphorus contents were 0.206 in one case and 0.05% in the second. CB

K Yamasaki, M Murozumi, S Nakamura, M Hinata, M Yuasa and M Watarai: Lead isotope ratios in some Japanese and Chinese bronze objects.
Archaeology and Natural Science (1979, pub in 1980), No 12, pp 55-65. In Japanese.

The lead isotope ratios of following Japanese and Chinese archaeological bronze objects were determined: 6 early Han mirrors, 11 late Han and other dynasty mirrors, 23 triangular-rimmed mirrors attributed to Wei, 6 mirrors made in Japan as copies of Chinese mirrors, 7 dotaku (Japanese bell-like objects), 2 arrowheads, 9 samples of the Horyuji pagoda and 1 sample of the pedestal of the main image of the Yakushiji temple. In addition 17 Japanese, 2 Chinese and 2 Korean galena ores were studied for their isotope ratios and the results were compared. The isotope ratios of the early Han and some late Han mirrors form the group (C) separated from that of the other late Han mirrors (B). The triangular-rimmed mirrors which are found only in Japanese tombs have isotope ratios similar to this B group. On the other hand Japanese dotaku and arrowheads show similar isotope ratios to those of the early Han mirrors, suggesting raw materials with the similar isotope ratios. The spire of the Horyuji pagoda and the pedestal of the main image of the Yakuschiji temple show similar isotope ratios with Japanese galena ores (group A). AATA

A B Avadhanulu: On the analysis of some ancient coins of the Satavahana Period.
Res Bull Birla Archaeol Cult Res Inst, 1979, **1**, *pp 13-26.*

Ancient coins of the Satavahana Period were chemically analyzed. A definite ratio of copper-to-tin was shown and the coins appeared to be fabricated from unrefined metals. Photomicrographs indicated the status of the alloys and structural features. AATA

W Epprecht: Forged wrought iron chain bridge containing arsenic-rich zones from the 14th century in Bhutan (Himalaya).
Arch Eisenhuettenwesen, 1979, **50**, *No 11, pp 473-477. In German.*

A chain link of the ancient wrought iron bridge was examined by metallography. In the mounting seam, there was a ferrite layer equal to or less than 0.1 mm thick with increased hardness and As concentration equal to or less than 2.6%. AATA

J Pelleg, J Barma and E Oren: Study of bronze artifacts from the North Sinai coast and the Nile Delta region.
Metallography, 1979, **12**, *No 4, pp 313-324.*

Three bronze objects from sites on the North Sinai Coast and the Nile Delta region were analyzed to study bronze technology in the region in ancient times. Metallography, microhardness testing and scanning electron microscopic analyses were performed. The artifacts were of different chemical composition, microstructure, and manufacturing process. AATA

E Stern: Achaemenian tombs from Schechem.
Levant, 1980, **12**, *pp 90-111.*

The report on the excavation of these tombs (6th-5th centuries BC) includes a chemical-metallurgical report on a bronze lamp and a bowl (A Lupu) and an analysis of some organic asphalt-like materials (Rosa Kopel). AATA

F Weinberg and E D Oren: Structure and composition of Roman Period metal artifacts from the North Sinai.
Can Metall Q, 1977, **16**, *Nos 1-4 (Metall Soc CIM; Annu Vol featuring Molybdenum), pp 147-155.*

Metallurgical techniques (optical microscopy, SEM, and the electron-probe microanalysis) were used to define where and how metal artifacts, of the Roman Period, from the North Sinai coast were produced. AATA

Africa

H M Friede: Iron Age mining in the Transvaal.
J S Afr Inst Min Metall, 1980, **80**, *No 4, pp 156-165.*

Archaeological studies of early mining activities in South Africa during the Iron Age are discussed. Chemical analyses of iron ore samples from archaeological sites in Transvaal are presented and mining sites for copper, tin and gold as well as iron are detailed. AATA

H M Friede: Iron-smelting furnaces and metallurgical traditions of the South African Iron Age.
J S Afr Inst Min Metall, 1979, **79**, *No 13, pp 372-381.*

An archaeological study is given of iron smelting processes in South African Iron Age furnaces and the characteristics of the smelting products. AATA

J Riederer: The dating of hollow cast Egyptian bronzes by means of thermoluminescence analysis.
Studien zur Altaegyptischen Kultur, 1978, **6**, *pp 163-168. In German.*

All clay cores in the collection of Egyptian bronzes of the Staatliche Sammlung Aegyptischer Kunst at Munich have been analyzed chemically and mineralogically. Different types of core materials exist. For 13 objects the absolute age was determined by different thermoluminescent techniques; reliable results with an error of + 12% were obtained. AATA

A Siff: Iron-smelting furnaces and the metallurgical traditions of the South African Iron Age. Comments.
J S Afr Inst Min Metall, 1980, **80**, *No 1, p 62.*

A polemic. Comments on the article of H M Friede. AATA

America

A H Rosenqvist: Material Investigations. A S Ingstad: The discovery of a Norse settlement in America.
Oslo University Journal, 1979, 373-404.

Iron objects excavated in the Viking site of L'Anse aux Meadows, Newfoundland, were shown to have been made from a low-phosphorus metal. There was presumably a small production of iron close to the site. Bloomery and smithing slags. Only one artifact was investigated metallurgically, from house F (ferritic iron with ca 0.2% P). The original raw material was probably bog iron ore. CPSA

Techniques

J N Barrandon: Activation analysis and numismatics.
J Radioanal Chem, 1980, **55**, *No 2, pp 317-327. (In French).*

Two nuclear methods are discussed which permit a non-destructive determination of major, minor, and trace elements in the archaeologically important metals Au, Ag, Cu and alloys.

Neutron activation analysis with a ^{252}Cf neutron source performs a fast and accurate determination of Au, Ag and Cu in the coins. Proton activation analysis determines trace elements at ppm level in Au, Ag and Cu metals. Using these two techniques of activation analysis two important numismatic problems can be studied; the evolution of fineness; and characterization or differentation by the trace elements the metal used to mint the coin. AATA

T I Berlin: A spectrochemical analysis of minute samples extracted from the objects of applied art and sculpture made of bronze.
Artistic Heritage, 1977, 2, No 32, pp 15-18. In Russian.

A combined spectrochemical method of examining elements in bronze objects and sculptures using minute samples in solvents. Accuracy of this method of many-component analysis is considerably increased. AATA

A Dey, A K Ghose and D K Shukla: A modified ring electrographic method for the non-destructive analysis of metallic artifacts.
Nature, Aim and Methods of Microchemistry; International Microchemical Symposium; 8th; Graz, Austria, August 25-30, 1980.

The ring electrographic technique is useful as a non-destructive method because it is accurate. The technique consists of the transfer of metallic ions from an artifact onto a filter paper, by electrography, and subsequently subjecting the transferred ions to analysis by the ring. In the present work, a filter paper is moistened with an electrolyte and the metallic object is placed on it directly in contact with an anode. The cathode is placed on the filter paper and metallic ions are transported to the paper. The object is placed with different points in contact with the filter paper, and both obverse and reverse sides are subjected to electrography Thus, the ions transported are representative of the whole composition. The paper cannot be subjected directly to the ring colorimetric procedure, since there is no regular spot, and the ions are extracted with 6N HNO_3 for ring colorimetry.

Details of the procedure and the results of the analysis of ancient Indian copper and silver coins obtained from the archaeological sites at Kausambi (Allahabad, India) are presented as well as data regarding age, composition, and sources of the ores. AATA

J Riederer: The contribution of metal analysis in the Rathgen Research Laboratory for Art History.
Jahrb Preuss Kulturbes, 1980, 15, pp 105-115. In German.

During the last few years, the Rathgen Research Laboratory in Berlin has analyzed 168 axes of the Bronze Age, 180 fibulae from the Celtic period, 64 statuettes from the Nuragic period of Sardinia, 164 pre-Columbian tools and weapons, about 100 Indian statuettes, more than 1000 Egyptian statuettes, 63 Chinese mirrors, 108 plates from Eskimo armor, about 600 bronzes from the Renaissance period and a great number of bronzes from other cultures. It has published valuable information for archaeology, ethnology and the history of art. AATA

S Sekowski and M Zawadzka: Measurement of thickness of non-typical metal coatings.
Ochrona przed Korozja, 1978, 21, No 11, pp 285-289. In Polish

Protection coatings with additional fillers, very porous or of unusually compact structure, are discussed, ie silver on ceramic ware. 'Thickness' must be defined. To obtain reliable data two values should be determined: the geometric thickness and the concentration of metal in the measured layer. The results depend not only on the characteristics of the layer, but also on the method used for measuring (ie microscopic, coulometric or complete dissolution). AATA

L Socha, S Safarzynski and M Lesiak: Production of decorative and protective oxide layers on large objects in outdoor exposition. (Bronzes).
Ochrona Zabytkow, 1979, 32, No 3, pp 208-220. (In Polish, English summary).

Described is a method of producing decorative artificial patina on bronze monuments, ie the work carried out on the figure of the Polish King Sigismond III Waza, in Warsaw After cleaning with a special paste (AATA 17-1614), a hot solution of NaOH and potassium persulphate was used to produce a layer of oxide. Theoretical background and details of investigation and tests are included. AATA

J Socha, M Lesiak ,S Safarzynski and K Lysiak: Oxide coating in the conservation of metal monuments: The column of King Sigismundus III Waza in Warsaw.
Studies in Conservation, 1980, 25, No 1, pp 14-18.

During conservation work in 1977 on the Column of King Sigismundus III Waza in Warsaw the old patina and the corrosive incrustation covering the metal parts were removed and replaced with an oxide layer. The thickness of this layer could be varied to give the required color. The oxide coating has better cohesiveness and mechanical and corrosion resistance than results from the use of traditional methods. AATA

E Szonntagh: Micro-sampling and analysis on early fifth century AD Roman bronze coins.
Nature, Aim and Methods of Microchemistry; Imternational Michrochemical Symposium; 8th; Graz, Austria, August 25-30, 1980, Abstracts; p 53.

Sampling valuable coins for analyses has always been problematic. Cutting, or even minute destruction, is undesirable, especially when historical or artistic values are at stake. The use of a one-millimeter drill, employed by the British Museum Research Laboratory for sampling larger pieces, would be prohibitive in the case of small coins, some of which do not even reach a thickness of 1mm. The so called 'non-destructive' methods have not been able to provide representative samples because of the non-homogeneous nature of most ancient alloys. Surface decorations, as well as corrosive and diffusive processes, may also alter the original composition of metal surfaces. A micro-sampling method for small coins has been developed. In a special fixture, the coins are sampled through their cylindrical surface by drill-bits of 0.6mm or less. The operation is conducted under a microscope. If necessary, the drilling can be repeated at different angles for more representative averages. The hardly visible drill-marks can be plugged, if unimpaired appearance is desirable. Several techniques were used for the analysis of dissolved samples including acetylene-flame Atomic Absorption Spectroscopy. Major and trace elements have been determined quantitatively in three coins (ostensibly originating from the same shipwreck). AATA

L J Love, L Soto and B T Reagor: Surface studies of ancient gold coins and modern copies by x-ray fluorescence, scanning electron microscopy and scanning Auger spectroscopy.
Applied Spectroscopy, 1980, 34, No 2, pp 131-139.

The composition, surface morphology, residues, elemental distributions and fabrication characteristics of a group of gold coins. Auger spectroscopy is of limited usefulness as light elements tend to reflect the recent history and handling of the coin. AATA

G R Gilmore and B S Ottaway: Micromethods for the determination of trace elements in copper-based metal artefacts.
J Archaeol Sci, 1980, **7**, *241-254.*

A combination of atomic absorption spectroscopy and neutron activation analysis for the chemical analysis of copper-based alloys is described. The method is intended for very small samples and enables up to 13 elements to be measured. Results obtained by the optimized procedure are compared with reference and laboratory intercomparison values. The possibility of provenancing copper artefacts by means of chemical analysis is discussed. BAA

M K Kalish: Technical requirements for artificial patina on bronze and copper monumental objects and methods of its examination.
Artistic Heritage, 1977, 2, *No 32, pp 42-53. In Russian.*

The requirements for physical and chemical qualities of artificial patina which constitute its ability to protect bronze and copper objects under practically any atmospheric condition are considered. These requirements are related to composition, structure, thickness, cohesion strength, abrasion firmness, elasticity (when bent), fragility (when scratched), and also to strength against chemical agents, temperature and moisture. The methods of investigation are described. AATA

R Foster and P Lott: Surface analysis of thick gold films by x-ray fluorescence using the base metal as an internal reference.
Microchemical Journal, 1980, 25 *,pp 176-178.*

The method presented allows the measurement of gold thickness on clad or 'gold filled' materials in situ. The base metal serves as an internal standard for a flat sample with exposed reverse. Regression analysis of one standard serves to calibrate other measurements. AATA

J R Dennis: Niello: a technical study. Papers presented by trainees at the art conservation training programs conference.
Center for Conservation and Technical Studies, Havard University, Cambridge, Mass, April 1979, pp 83-95.

Technical study of the pigment niello, which was used to heighten engraved and chased ornament and inscriptions on silver objects and was also found on gold and bronze objects. A history of its use, properties, manufacture, application, and a full scientific analysis using a variety of techniques are provided. AATA

The abstracts are now being edited by Dr Paul Craddock and the Honorary Editor would like to acknowledge his help and that of many others. He is very grateful to the following who are actively participating:- D R Howard, J W Butler, P S Richards, H F Cleere, H W Paar, N Mutton, M Goodway, A P Greenough, J K Harrison, W A Oddy, M M Hallet, J Piaskowski, D G Tucker and E C J Tylecote. 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 the Council for British Archaeology who allow us to use material from their abstract journal, British Archaeological Abstracts (B A A) and to Miss C Lavell the editor. Finally, through the courtesy of Dr R Pleiner, honorary secretary of the Iron Committee of the International Union of Prehistoric and Protohistoric Sciences (CPSA) we are allowed to reproduce items from the Bulletin of that Committee.