HISTORICAL METALLURGY

REPRINT EDITION

JOURNAL OF THE HISTORICAL METALLURGY SOCIETY

The Historical Metallurgy Society has published the results of research into many aspects of the history of metals since 1963. As interest in the subject continues to increase, the Council decided, as a matter of principle, that it should ensure all publications of the HMS remain available for purchase in some form or other.

The very earliest regular publications were known as Bulletins. Of these numbers 1 to 6 (inclusive) covering the years 1963 to 1966, have been reprinted bound into one volume. Bulletins for the years 1967 to 1974 (fifteen issues in total) are available.

Since 1974 the Society's publications, produced twice each year, have been entitled *Historical Metallurgy,* the Journal of the Historical Metallurgy Society, and every endeavour has been made to maintain stocks of original editions. Since, however, this has not always been possible arrangements have now been made to produce facsimiles in the most economical manner whilst still preserving the essence of the original volumes.

Since the *Journal* (formerly *Bulletin)* of the Historical Metallurgy Society began to be professionally printed in 1966 it has been customary to use a cover illustration with both historical and metallurgical connotations.

Usually there has beena deliberate link with an item appearing in that particular Volume, a policy which posed a problem when the Society decided to introduce Reprint Editions, which for technical reasons could not appear with the original cover illustrations.

However if the development of metal working is considered alongside the history of printing it is quite clear that Gutenberg owed a great deal to the art of the pewterer.

In Biringuccio's *Pirotechnica,* which was published in 1540 and is the first printed book on metallurgy, there is a description of type-founding which is in itself the earliest known record of the subject and so therefore it is quite appropriate to use a wood engraving of an early print-shop.

The illustration is from *De Sabbaticorum Annorum Periodis Digestio* published by R.Pont in 1619.

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Bulletin of the Historical Metallurgy Group

Preparing bloomery iron for treatment. Agricola Book IX

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Copper smelting experiments

J.W. ANSTEE

Museum of English Rural Life, Reading

The examination of mines and smelting sites worked in Austria during the Bronze Age has shown that the pyritic copper ores were extensively worked. As these ores need prolonged and skilled treatment using even modern methods, the purpose of the following experiments was to ascertain how the raw material would react to 'primitive' techniques used in conjunction with a comparatively simple furnace and allied gear. The blacksmith's shop at the Museum of English Rural Life was selected as a site for the furnace because conditions of purely natural draught could be enforced and variable wind gusts nullified.

THE EXPERIMENTAL FURNACE

A platform of bricks bedded in local clay served as the furnace foundation, and a small area of its surface was covered with an insulating layer of mixed sand, charcoal, and wood ashes. This was covered by a sandstone slab (8in x 9in) to form the base of the crucible. It was surrounded on three sides by similar slabs insulated in the same way. They projected 6in above the base. The slab forming the back of the pot leaned backwards at 75° away from the future blast aperture in the manner of the Catalan hearth. The front wall of this crucible consisted of small pieces of sandstone in order to facilitate a rapid breakdown at the conclusion of a smelting run. The interior of the crucible was lined with a wet mixture of fireclay grog and charcoal so that it formed a shallow circular basin 9in in diameter and 3in deep.

A circular-sectioned shaft was superimposed above the crucible, but a large aperture was left for the tuyere and other air ducts. The shaft tapered from 9in in diameter at the bottom to 7in at a height of 6in, remained at 6¾in diameter for the next 4in, then opened out to 7½in at 1ft 11in of vertical height. Up to this point the shaft was built of twelve layers of wedge-shaped sandstone blocks. All vertical joints were staggered, and the blocks of the first five courses were bedded in a mixture of clay, sand, and ashes. The seven top courses were bedded in plain

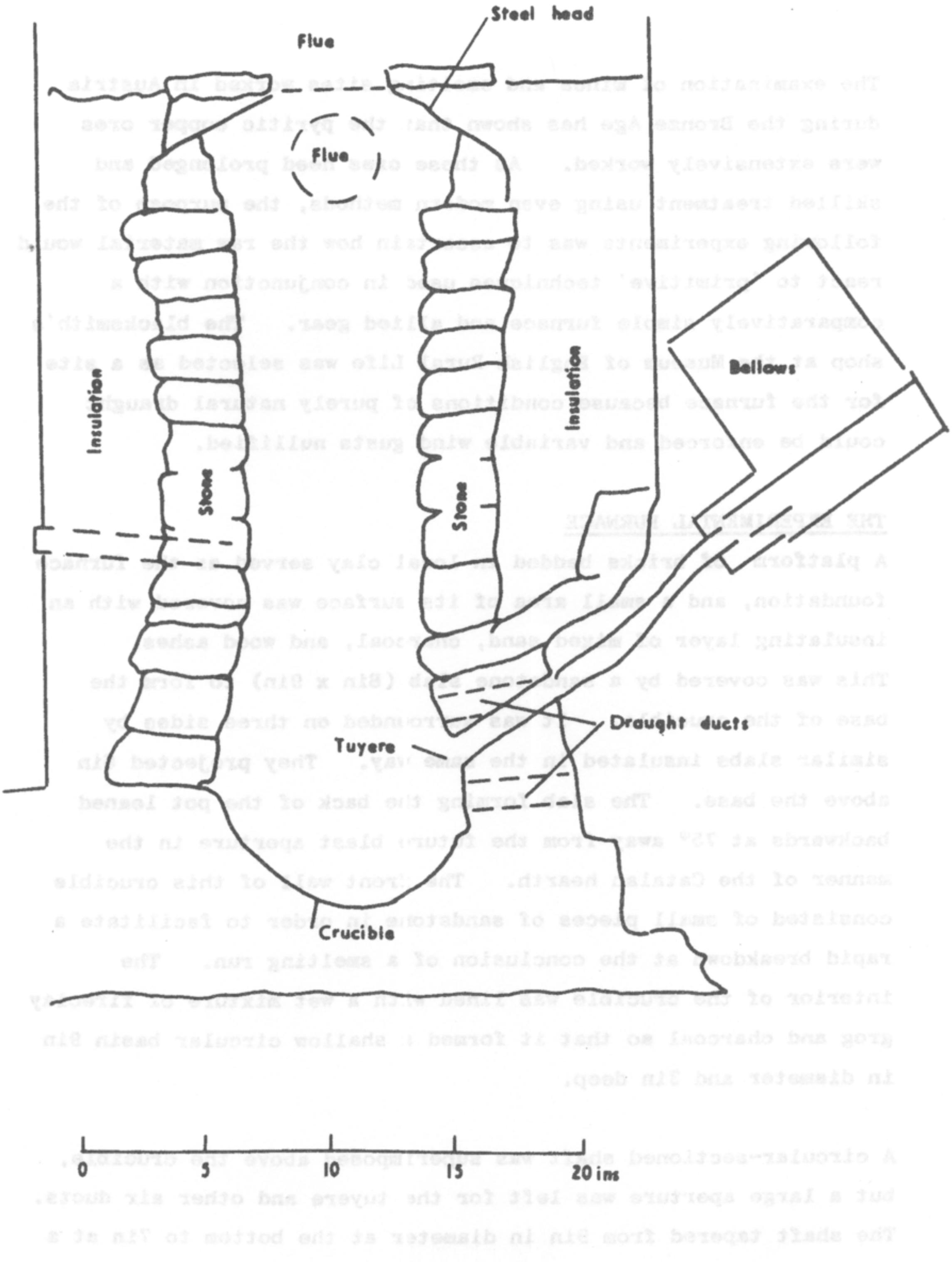

Fig.1 - Section of experimental furnace

local clay. The shaft walls averaged 3½ - 4in thick. All the sandstone used in the furnace was roughly hammer-trimmed from Victorian paving slabs.

The shaft was surmounted with a coned steel cap having a 4½in diameter hole at its apex. The cap measured 10in in diameter and 5in deep, and had old sandstone and clay packed inside its lower edge to act as a seal. A cast-iron drain pipe was inserted into one side of the cone to function as a chimney should the top vent need to be dammed up. A square casing of planks was built around the masonry core to retain the sand layer poured in between the two. A steel pipe ran through boards, sand, and core to enable a study of interior furnace conditions to be made occasionally.

The furnace was dried out gradually; too swift an application of heat would have caused the stones to explode violently. A number of firing runs were carried out using <u>no</u> ore. They were primarily to ascertain the capabilities of the furnace using wood and charcoal of varying sizes.

Using natural draught only and walnut-sized charcoal, the <u>charge</u> was worked up to a bright red heat. These conditions existed to a point about half-way up the furnace, although a good yellow heat was apparent just above the crucible. It was found useless to use very small charcoal and dust with natural draught, as it effectively chokes the furnace.

Thus it was proved that natural draught alone is sufficient to attain fairly high temperatures using carefully graded charcoal and keeping the areas of shaft, chimney, and induction aperture to certain ratios.

In the run without ore, the areas were:

<u>Top</u>	$19in^2$	approximately ratioed at	1
	$38.3in^2$		2
<u>Bottom</u>	$36in^2$		2

For the purposes of the first true run with ore, the large induction aperture at the bottom was replaced with six horizontal fireclay cylinders, each having an internal diameter of 1.06in. This altered the flue ratio to:

Top	19in^2	approximately	3
Shaft	38.3in^2		6
Induction	6in^2		1

At the same time another fireclay cylinder was incorporated between the others to act as a tuyere for forced draught. It sloped downwards with the crucible at an angle of 33° to the horizontal.

A test run using dry wood as fuel gave the following results. Small wood fed down the shaft charred itself automatically on the way down and continually filled the crucible with charcoal. The application of a gentle air blast soon brought this charge up to white heat in front of the flue. (It is important to keep the initial wood fire burning only in the bottom quarter of the furnace. Too generous stoking only wastes wood with inefficient combustion and volumes of smoke ensuing).

Fragments of clay furnace fettling became detached and in falling changed to a cinder slag which, on cooling in front of the flue, tended to obstruct the air supply. These were easily poked away through one of the natural draught apertures, which incidentally had been dammed up with wet clay when forced draught was applied. This stops the inevitable blowbacks which normally ensue if this is not done.

<u>Tentative conclusions about the nature of shaft furnaces</u>

(1) The shaft effectively produces charcoal from a dry-wood preheating charge.

(2) It forms an efficient chimney when heating up, resulting in increased draught speeds (when no forced draught is used).

(3) It preheats the final charcoal and ore charges, giving better facilities for reduction when needed.

(4) It effectively concentrates the deposition of the charge products into the crucible.

(5) It is not necessarily to be considered as containing red-hot charcoal and ore right to the top under natural-draught conditions, especially when the shaft is very tall in relation to its diameter.

EXPERIMENT 1

A small quantity of pyritic copper ore was obtained and broken to thumb-nail size with the hammer. On a hard surface this was fairly easily done, but the massive pyritic crystals tended to crush to a powder.

A small amount of the ore was subjected to intense roasting under a gas-air torch. Rapid heating created violent explosions and quite dangerous flying fragments. Volumes of white smoke were soon emitted; much SO_2 was evolved. The rapid physical disintegration tends to confirm Agricola's statement that first roastings (at least for mattes) should be done at a low heat.

The rest of the ore was brought up to a low red heat on fireclay slabs placed over the forge fire. It remained at temperature for about half an hour, with occasional stirring to facilitate oxidation. There were no white clouds of gas given off, but plenty of SO_2 was being produced and the pile burnt sporadically with a blue flame around its edges. The roasted ore was dumped into water, washed, and drained and the calcined stones were sorted out.

The larger lumps had their exteriors coloured to a light orange-brown, to a depth of 1/16in. Their interiors had a loose sandy texture black in colour. Only a very small amount of unchanged yellow pyrites could be seen.

The lumps crushed very easily to a coarse powder and this was dried and weighed, giving 2½lb; this was made into a stiff paste with about $10in^3$ of soft local clay and kneaded into 38 walnut-size balls which were allowed to dry out naturally.

Operational Sequence, 20.4.60

0900 Lit up and running under natural draught with wood as fuel. Top soon banked up with red-hot charcoal.

0930 Stoking down shaft every 10min with five or six pieces of wood averaging 6in long and 1¼in diameter. Fire kept well to bottom of shaft all the time. Slight bursts of smoke when stoking but soon cleared. Re-stoked when each charge had nearly burnt out. Generally flaming 8in out of top vent.

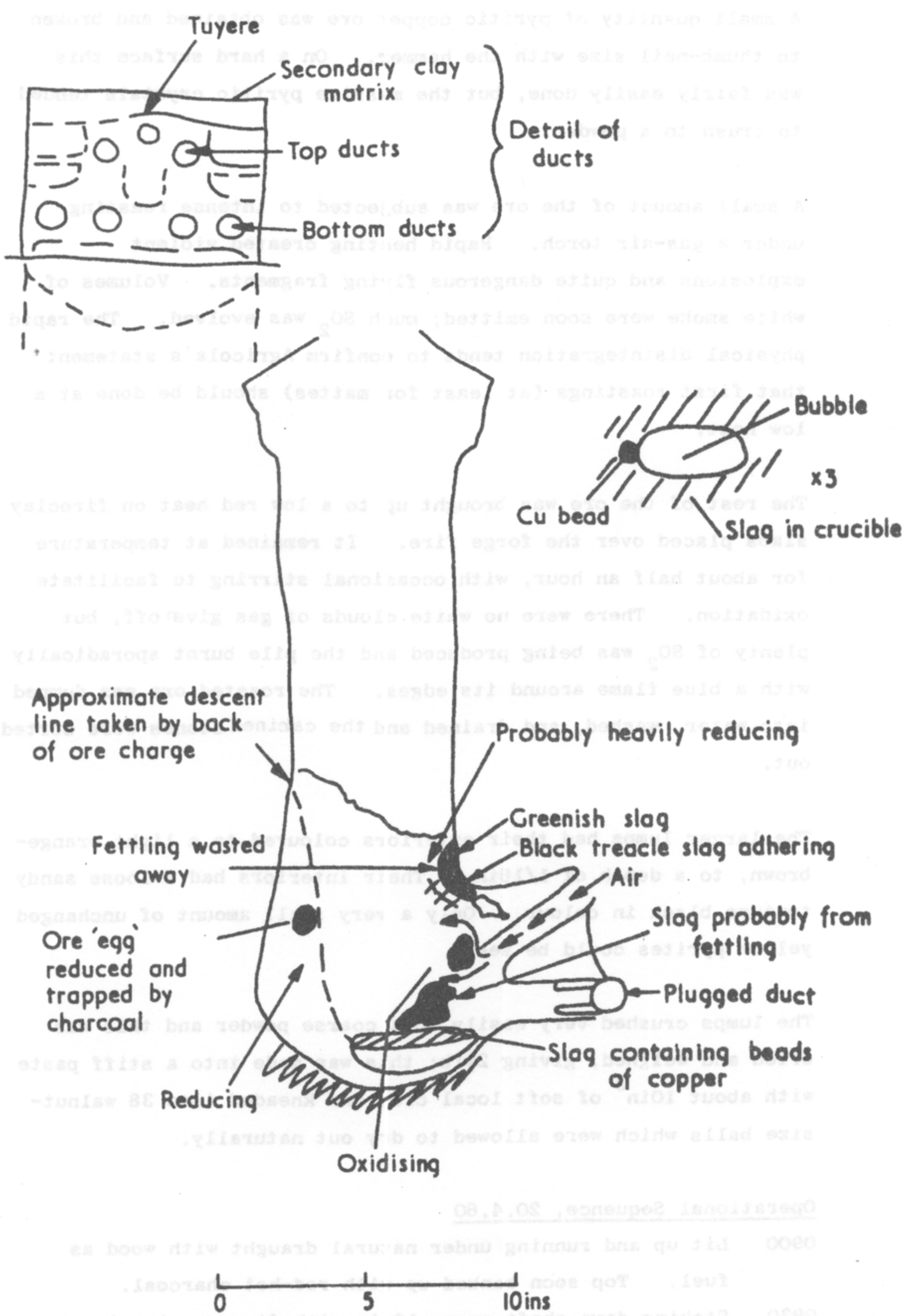

Fig.2 - Position just before blowing out at 1340

0945 Top vent reduced to $8in^2$ (side chimney vent open). Future charges of wood stacked around top vent for drying. Did not pay to overstoke. Bottom few air ducts kept the pot charcoal at an orange heat. Top two ducts served burning wood in shaft.

0950 Edge of steel-covered cone glowing red.

1018 Lower portion of furnace to the level of the air duct lintel glowing red. Charcoal level in pot kept uniformly just above the lower ducts.

1030 Stoking every 6 min.

1130 Stoking every 4 min.

1200 Whole of interior of shaft up to the top at a bright red heat (side spyhole remained open until 1200).

<u>End of preheating stage</u>

1200 Spyhole and six lower ducts sealed with pads of soft clay. Shaft filled with walnut-size charcoal to within 5in of top. First charge (6 lumps) of ore in, followed by 2½in of small charcoal. Very gentle blast applied - approximately one double stroke of the piston per second.

1210 Coarse charcoal seen through spyhole to be blood-red. At tuyere level a yellow white heat. Plenty of blow-back through air ducts when unstopped to look through (bellows have to be shut off when doing this). Second charge of ore and charcoal in.

1217 Third charge in.

1219 A little arsenic coming through spyhole. More at the top vent. Top gases lit deliberately (not naturally). Mixture of blue monoxide flame and yellowing monoxide flame 2ft high.

1226 Fourth charge in.

1228 Plenty of arsenic noted from spyhole. SO_2 from all bottom ducts when unstopped. Also a little SO_2 from top vent. No SO_2 from spyhole.

1233 Increasing arsenic at top and plenty of SO_2 tending to be uncomfortable for operator at top of furnace.

1240 Occasional green tinge to top flame. Area around tuyere red-hot well towards outside of furnace.

1242 Fifth and last charge of ore in, plus 8in of charcoal to cover.

1245 Plenty of arsenic and SO_2 at the top and at spyhole.

1250 Not so much arsenic and SO_2 coming off.

1253 Arsenic from spyhole but no SO_2.

1300 No SO_2 at top; green-tinged flame, tends to be violet at times when blast is stopped.

1305 More arsenic at top. Charge of charcoal etc. at a dull red heat to the top within 7in of shaft top.

1310 Green tinge shows up better when not blowing.

1318 Still arsenic at top.

1324 Cold mass of slag in front of tuyere restricting blast. Poked away through duct. Immediately obtained better oxidizing conditions at this point; more SO_2 from top.

1325 No arsenic at top. Plenty of SO_2. Purple-violet flame in shaft.

1335 More arsenic at top. Charcoal level at just above top of lintel.

1340 More slag in front of tuyere - plenty of arsenic still coming off and small amount of SO_2. Surface of slag in pot basin felt slightly viscous when poked. Blown out and shut down.

Results

Breaking open the tuyere wall revealed that a considerable amount of its clay had run to a black slag, particularly a glossy black in the interstices around the tuyere and two upper air holes. A slag arch existing with its crown just above the tuyere had its two curving pillars falling right and left between the right and left pair of lower air ducts. This slag is assumed to have been derived from the fusing clay packing. The arch was joined to the surface of this slag, filling the crucible concavity. The latter was filled to just below the level of the bottom of the lower air ducts. The mass extended backwards for three-fifths of the depth of the crucible. It was levered away from the latter and showed a thin layer of glowing charcoal underneath. This extended upwards at the back of the furnace in the form of a near vertical wall of red-hot charcoal for a considerable height. The charcoal lumps were identifiable as those from the primary charge of large charcoal. It contained one porous ball of made up ore (fired to a hardish grey).

The sandstone wall of the furnace above and to the right and left above the tuyere had moderate slag incrustations.

The crucible filling was cooled in water and broken up. It had consisted of two main layers besides the slag arch adhering to its upper surface:

(1) A grey-black very porous layer 1in thick, not vitreous in quality but slightly sintered cinder. No visible traces of metallic copper in it.

(2) A layer of slag covering all the surface of (1). It contained two fragments of matte each about 3/8in cube and each trailing off into slag.

Some bubbles in the slag when broken had their inside surfaces covered with metallic copper. A copper bead about 3/32in in diameter was imbedded in the wall of one bubble and had evidently been under pressure when molten, as part of its surface conformed to the rim of the interior wall of the bubble. About five other pieces of metallic copper were found, all imbedded in the slag (but not in bubbles). The largest measured 3/8in long, 3/16in wide, and 3/32in thick. It appears to be remarkably pure copper. This is in contrast to one or two others which may have a high sulphur content.

Conclusions

Future damming of the furnace mouth will have to be done using as little secondary clay as possible owing to its clinkering tendency. Such an addition to the crucible fill could possibly upset the ratios between matte and slag.

The reducing zone at the back of the furnace would probably not exist if more blast were used, but it may partly depend on the tuyere angle. The amount of fuel used was surprisingly small.

(1) Preheating period: about $3ft^3$ of stacked small billets of wood broken from small dry branches.

(2) Reducing period: about $1\frac{1}{2}ft^3$ of elm and oak charcoal.

The average rate of descent of the charge down the shaft averages out at about 1ft every 25min. Air was used at the rate of $15ft^3$/min, i.e. about $1500ft^3$ for the 'blast' run of 1 h 40 min.

Specimens preserved

1. 'Egg' of reduced ore and clay (broken to show interior of structure).
2. Specimens of metallic copper from bubbles in slag.
3. Two pieces of matte from slag.
4. Specimen of raw ore (Chalcopyrite)

Contents of furnace pot and adhering lumps of slag crushed up. Roasted in base of furnace (front of pot removed) for about 1 h. Continually stirred with violent air blast from box bellows and free air. Small amount of charcoal as fuel. Very faint traces of arsenic coming off but nothing spectacular or appreciably noticeable.

Notes concerning copper smelting

WERNER LORENZEN

From 'Helgoland und das früheste Kupfer des Nordens' (Ottendorf-Niederelbe 1965)

We cannot say much about the earliest smelting furnaces in which oxide copper ores were smelted since remains of such furnaces are not known because, after each smelt, the furnace when cooled down was destroyed in order to extract the copper. In the course of time increased production and developed methods will also have obliterated evidence of the earliest working.

The free standing furnaces at Vučedol on the Danube* are not smelting furnaces, but are apparently for melting copper bars. Hence, they do not advance our knowledge of smelting technique except in so far that they show that the furnaces of this period were simple, but very carefully constructed.

In considering our experiments we have postulated that the discoverers of the art of metal smelting, that is the first metallurgists, will only have used a charcoal fire without artificial blasts. To attain a sufficiently high temperature to smelt the copper and to slag the gangue if possible, and also to avoid too much air flow from the upper surface, we experimented with a pit of about 70 cm in diameter and 30 - 40 cm in depth which was made in a built-up mound. The bottom of the pit therefore lay at the same level as that of the surrounding surface of the ground. A furnace lining was omitted although this would have been an advantage for the stability of the furnace; merely a 10 cm clay (pottery) tube was provided on the windward side to serve as a furnace entrance or wind passage. Two earthen walls 1.5 m in length were provided to act as wind passages to increase the draught when a strong wind was blowing.

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* R.R. Schmidt : "Die Burg Vučedol", 1945.

Roughly broken copper oxide ore (see Table I) was put into a clay pot (coarse baked) of 15 cm in diameter together with one-tenth its volume of charcoal. The pot was placed in the middle of the pit on a small layer of charcoal. The rest of the space in the pit was heaped with charcoal which was ignited through the furnace entrance passage. At the start the air passage was throttled, but within 1 h the charcoal was all ignited, and in 3-4 h full heat was attained. Then the wind passage was closed, the pit was covered with sand, and the furnace was allowed to cool down overnight.

On examination it was found that the ore in the clay pot was sintered together and turned to a dark brown colour. The greater part of the ore was reduced and formed small balls of copper of up to 1 cm in diameter. These were partly on the bottom of the vessel and partly still lodged in the cracks and hollows of the parent stone.

In further experiments under almost windless conditions the ore was reduced, as shown by bright copper-red zones in the ore, but the melting temperature was not attained. Finally, in a third experiment with stronger wind conditions the heat softened the clay pot so that at the end of the trial the pot was quite deformed and one side split open. This time, the 'unprotected' pieces of ore were mostly melted to porous pieces in which bright balls of copper were dispersed throughout. Owing to their brittleness the porous pieces of slag were easy to break and powder, so releasing the ductile balls of copper. These fundamental experiments showed that it was simple to obtain copper from the oxide sandstone ores of Heligoland, but such experiments were time-consuming and expensive in charcoal because they are dependent upon variables such as the direction of the wind, etc. Hence, we decided to carry out some experiments under controlled conditions of temperature and time, in order to learn more of the necessary smelting conditions. These trials were made in an electric furnace with temperature control. A covered graphite crucible of 2 litres capacity was used to simulate the furnace atmospheric conditions. The ore was packed with charcoal in the crucible and covered with a thin layer of

TABLE I

Analyses of Heligoland copper ores

(1) Red-brown mottled sandstone from boundary area of upper and lower part of middle Bunter sandstone.

(2) Pale green mottled sandstone from same area as (1).

(3) Blue-green sediment of red-brown sandstone. The assay was made on coloured coarse crystallized calcite which included light blue-green material that had disintegrated into powder.

(4) 5-20 mm thick green layer between very soft crumbly grey-white sandstone of the upper part of the lowest section of the middle Bunter sandstone. The green layer has areas dotted with dark-brown and black. The vein was removed up to the beginning of the green area.

(5) 20-30 mm thick dark-green layer, with many dark-brown specks and grains of pure copper.

(6) Dark-green to brown particles of layer (4)

(7) Brown piece of ore, mainly consisting of cuprite.

%	1	2	3	4	5	6	7
Cu	0.048	0.10	7.9	10.8	23.2	24.1	43.5
As	0.0005	n.d.	n.d.	0.11	0.39	0.44	n.d.
As in 100 parts Cu	1	-	-	1	1.7	1.8	-
$Al_2O_3 + Fe_2O_3$	17.5	5.7	1.3	n.d.	16	1.5	n.d.
CaO	n.d.	n.d.	25.6	0.2	3.2	2.2	n.d.
Bi	n.d.	n.d.	n.d.	n.d.	n.d.	tr.	n.d.
Sb	n.d.	n.d.	n.d.	n.d.	n.d.	tr.	n.d.
SiO_2	53.5	74.4	n.d.	56.4	43.3	45.4	19.1
CO_2	little	little	much	n.d.	n.d.	10.1	n.d.

n.d. = not determined

charcoal; the crucible being closed with a graphite lid. The crucible was slowly heated (in 1 - 2 h) to the test temperature, and then held at this temperature for 4 h before removal for cooling. The results were as follows.

At considerably under 1000°C the charge of oxidized copper (ore) was reduced to brown-red metallic copper. Above 1000°C these particles compacted to small balls without the parent stone melting or sintering. These copper balls were found partly in the cracks and hollows that formed in the parent stone during the heating, and partly dropped to the bottom of the containing vessel. At about 1150°C the sandstone melted to a porous slag and the quantity of small, and very small, copper balls (about 5 to 0.5 mm) was markedly increased. At 1250°C a general degassing slowly set in, and the smaller copper balls began to unite and collect at the bottom of the smelt. Even at 1300°C, the limiting temperature of the electric furnace (this is also approximately the upper temperature that can be reached under the most favourable conditions in the charcoal-fired field furnace), and with 4 h heating, many small copper balls still remained in the slag. Even after this time the degassing, while general, was not fully completed, as shown by the still relatively considerable toughness of the slag melted at this temperature.

For these experiments, broken ore with an average copper content of about 8-12% was used (not particularly rich pieces). From an experiment at 1250 - 1300°C the charge and products were:

Quantity of ore	1240 g.
Copper as small balls (over 1 mm in diameter)	69.5 g.
	= 5.6%

The amount of copper remaining in the slag, partly metallic and partly in chemical combination, was 3.2% of the original raw material.

The total yield was about 8.8% of the charge, which probably did not contain more than this proportion of copper.

Spectographic analyses were made of the copper obtained from the various smelting experiments:

Experiment 1. T1 - T5 Smelted at 1000-1050°C
(Parent stone not yet melted)

Experiment 2. T6 - T9 Smelted at 1200-1250°C
(Parent stone melted; very porous)

Experiment 3. T10 - T14 Smelted at 1250-1300°C
(Parent stone melted; generally degassed)

T1 - T14 are from the larger of the small copper balls. In the case of T8, T12, and T14, some small balls were melted under charcoal into small bars. These results are given in Table II.

TABLE II Spectrographic analyses of copper smelted from Heligoland ore (%)

	Sn	Pb	As	Sb	Ag	Ni	Bi	Zn	Co	Fe
T1	0	0.7	1.0	0	0.29	0.01	0	0	0	+
T2	0	0.04	0.82	0	0.11	0	Sp	0	0	+ +
T3	0	0.18	0.54	0	0.05	0	0	0	0	+ +
T4	0	0.7	0.31	0	0.02	0	0	0	0	+ +
T5	0	0.16	0.51	0	0.05	0	0	0	0	+ +
T6	0	0.02	1.55	0	0.21	0.03	0	tr	0	+ +
T7	0	tr	1.35	0	0.09	0.01	0	0	0	+
T8	0	0.06	2.2	0	0.24	0.06	0	0	0	+ +
T9	0	0.07	2.1	0	0.25	0.07	0	0	0	+ +
T10	0	0.03	2.4	0	0.45	0.05	0	0	0	+ +
T11	0	0.02	2.6	0	0.42	0.04	0	0	0	+ +
T12	0	0.12	2.0	0	0.4	0.06	0	tr	0	+ +
T13	0	0.12	1.4	0	0.31	0.05	0	tr	0	+ +
T14	0	0.12	1.7	0	0.33	0.03	0	tr	0	+ +
T3) to) T14)	tr	0.07	1.1	tr	0.18	0.02	0	0	tr	+ +

\+ Present. + + Strong trace.

From the ore and metal analyses it is shown that the trace elements present in the ore are also found in the metal that has been smelted from the ore. However, apparently only lead and arsenic (at high temperature) translate fully and quickly, whilst the translation of tin, antimony, nickel, bismuth, zinc and cobalt may be rather more difficult or slower. The highest and lowest values of the ore and metal analyses for the different elements give the range within which the metal smelted from the Heligoland ore can vary. The limits are approximately:

Sn 0 to 0.09%	Pb Tr to 0.17%	As 0.3 - 2.6%
Sb 0 - 0.17%	Ag 0.02 - 0.45%	Ni 0 - 0.16%
Bi 0 - 0.0025%	Zn 0 to tr.	Co 0 to tr.

The probable values lie between these limiting figures. Naturally, it must be accepted that these figures may vary for other parts of the ore-body. Further experiments showed that the trace elements remained in the metal after various melting processes, reactions, etc.*

We can sum up by saying that the composition of the raw copper considered here is astonishingly constant under various conditions, and that during the 'static' smelting appreciable changes in composition only occur with great difficulty. This means that it is also probable that under the smelting techniques of the first metallurgists (which are not known today), the composition of the metal remained a characteristic of the ore smelted.

WORKING OF COPPER

Some forging tests were made with a piece of Lake Superior native copper. Initially the piece of native copper was 6 - 7 mm in thickness. After two or three forgings with intermediate anneals some slight cracks were observed at the edges. However, with intermediate anneals it was possible to forge the metal into a sheet without appreciable increase of cracking, thus:

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* Translator's Note. In short, it is found that the trace elements persist in a remarkable manner from the raw material, ore, through to the finished product.

After 5	forging	operations	the	thickness	was	4.0 mm
" 10	"	"	"	"	"	2.0 mm
" 15	"	"	"	"	"	1.5 mm
" 30	"	"	"	"	"	0.5 mm

The surface area increased to 25.5 cm^2

In a further experiment, a ball-shaped piece of the Heligoland smelted arsenical copper of 6.85 g weight, after 25 forging operations gave a sheet of 16 cm^2 area and of thickness 0.2 - 0.4 mm. It was possible to give this copper an excellent polish and objects were experimentally made from it. The above is all wrought work, no melting or cutting being involved.

FORGING A COPPER SPIRAL

An experimental spiral was forged for the author from arsenical copper by Hans Drescher of Hamburg. A bar was cast measuring 8 x 10 x 66 mm. From this, twelve forging operations with intermediate anneals produced a wire of square cross-section 67.5 cm in length. The desired cross-section for the spiral can be obtained by hammering the wire into a die or template. In the case of the spiral made by Drescher, hammering the wire into a die required a further two anneals, and increased the length of the wire to 80 cm, giving a characteristic D profile. After profiling and annealing the wire can easily be wound round a mandrel of the necessary diameter to form the spiral. (20 mm diameter. 50 mm in length, with 12 coils. Working time 2 h).

FORGING A COPPER FLAT AXE

The forging of a copper flat axe presents no more difficulty than the spiral just mentioned, only more raw material is required. Starting with a blank of 10 x 50 x 140 mm, one side of the axe was completed in eight forging operations with appropriate anneals. The width increased to 75 mm and the length to 150 mm. The cutting-edge was forged to 0.25 mm, from which thickness it could easily be ground to knife sharpness.

(Free translation from the German text by H.H. Coghlan)

Analyses of Trojan bronzes

(prepared by Dr and Mrs R.F. TYLECOTE from information supplied by Dr Robert I. JAFFEE)

By the courtesy of one of our members, Dr Robert I. Jaffee of the Battelle Memorial Institute, Columbus, Ohio, a number of analyses of Trojan bronzes have been made available for publication by the Historical Metallurgy Group.

The main excavators of Troy have been H. Schliemann (1) and Professor C.W. Blegen of the University of Cincinnati (2,3). In 1936, a paper was presented to the British Association Meeting at Blackpool with the title "Sumerian Copper". It constituted the Seventh Interim Report of the Committee appointed to report on the probable source of supply of copper used by the Sumerians. The secretary of this committee was the late Dr C.H. Desch, who presented the report, in which the analyses of 14 Trojan bronzes were given. In fact, these analyses comprised the greater part of the analytical material of the report. The analyses were actually made by Metallurgy Department of the National Physical Laboratory. In his report, Dr Desch stated that a second series of specimens had been received from Professor Blegen but that they had arrived too late for inclusion. It was suggested that £100 should be contributed by museums and others as a fund for further analytical work.

It seems that this second group of 25 specimens received from Professor Blegen, which no doubt represented material excavated in the 1930's, was not in fact analysed until after the war. The results arrived too late for inclusion in Blegen's reports on Troy (2) published in the 1950's and have therefore remained unpublished.

These results, together with the original 14 analyses published in the British Association paper, have been collected in Table I of the present paper. Reference A identifies the first (published) series and B the hitherto unpublished results.

The two figures show the specimens as received; the scale is full size.

Table II gives the chronology of the site and some details of the archaeology. The 39 specimens cover a period of about 2000 years and from their composition we can obtain a fairly clear picture of the change in metallurgical fashion during the period 3000 - 1000 B.C.

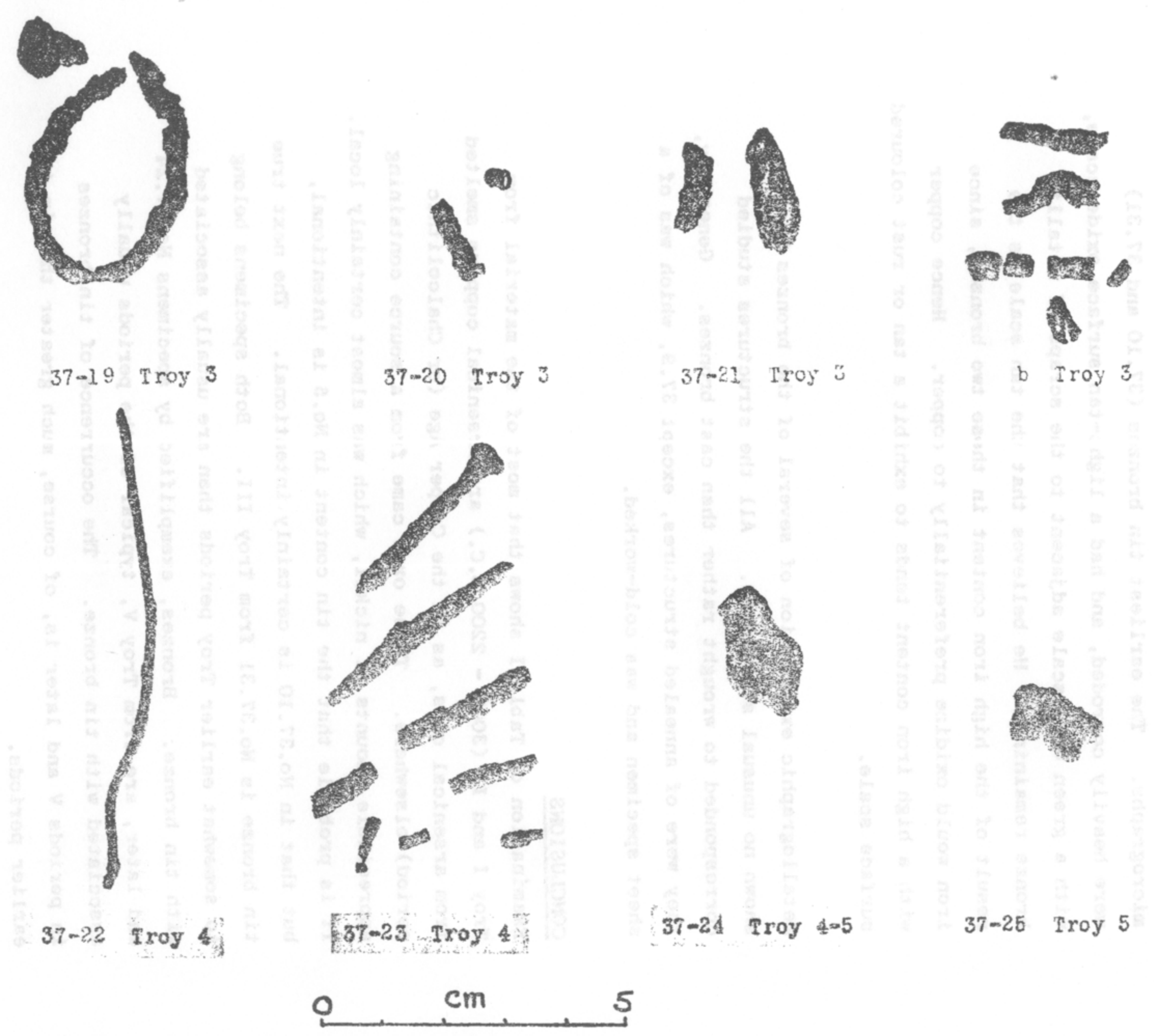
Dr Jaffee has supplemented the chemical analyses with some micrographs. The earliest tin bronzes (37.10 and 37.31) were heavily corroded, and had a light-tan surface oxide scale, with a green underscale adjacent to the scraps of metallic bronze remaining. He believes that the tan scale is the result of the high iron content in these two bronzes, since iron would oxidize preferentially to copper. Hence copper with a high iron content tends to exhibit a tan or rust coloured surface scale.

Metallographic examination of several of the bronzes has shown no unusual structures. All the structures studied corresponded to wrought rather than cast bronzes. Generally, they were of annealed structures, except 37.9, which was of a sheet specimen and was cold-worked.

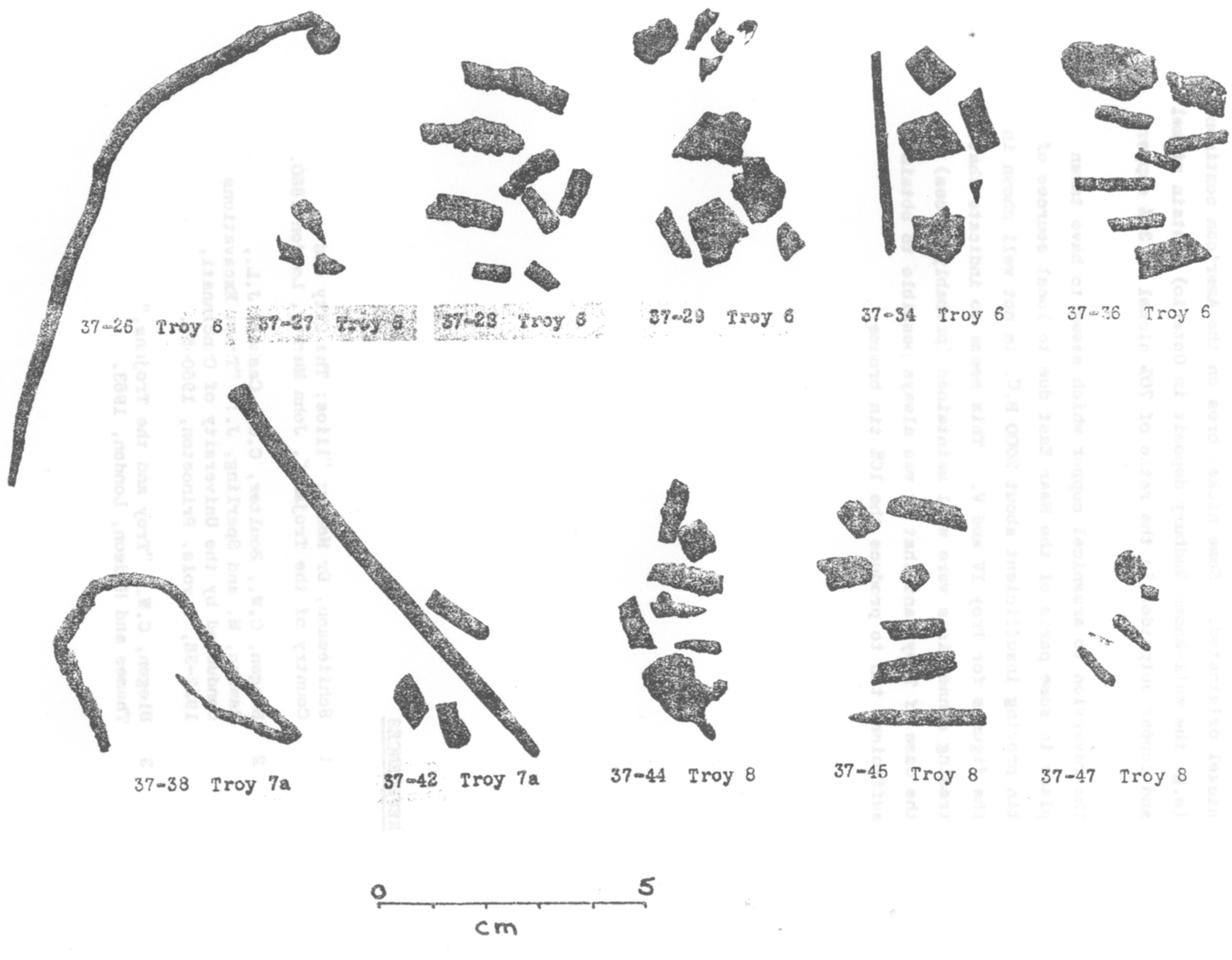
CONCLUSIONS

Examination of Table I shows that most of the material from Troy I and II (3000 - 2200 B.C.) are arsenical coppers smelted from arsenical ores, as in the Copper Age (or Chalcolithic period) elsewhere. These ores came from a source containing appreciable amounts of nickel, which was almost certainly local. It is probable that the tin content in No.5 is intentional, but that in No.37.10 is certainly intentional. The next true tin bronze is No.37.31 from Troy III. Both specimens belong to somewhat earlier Troy periods than are usually associated with tin bronze. Bronzes, exemplified by specimens No.37.24 and later, are from Troy V, typical of the periods usually associated with tin bronze. The occurrence of tin bronzes in periods V and later is, of course, much greater than in the earlier periods.

Specimen 37.38, from Troy VII, contains almost 10% nickel, typical of a cupro-nickel alloy. This indicates a new type of bronze, which might be termed nickel bronze. Technically,



37-19 Troy 3
37-20 Troy 3
37-21 Troy 3
b Troy 3
37-22 Troy 4
37-23 Troy 4
37-24 Troy 4-5
37-25 Troy 5
0 cm 5



37-26 Troy 6
37-27 Troy 6
37-28 Troy 6
37-29 Troy 6
37-34 Troy 6
37-36 Troy 6
37-38 Troy 7a
37-42 Troy 7a
37-44 Troy 8
37-45 Troy 8
37-47 Troy 8
0
5
cm

this type of alloy is cupro-nickel, and typically contains 10 - 20% nickel. Consideration should be given to where the nickel originated. Some nickel ores on the American continent (e.g. the well-known Sudbury deposit in Ontario) contain nickel and copper sulphides in the ratio of 70% nickel to 30% copper.

The reversion to arsenical copper which seems to have taken place in some parts of the Near East due to local sources of tin proving insufficient about 2000 B.C. is not well shown in the figures for Troy IV and V. This seems to indicate that trading connections were well maintained (probably by sea) in the case of Troy, and that it was always possible to obtain sufficient tin to produce the 10% tin bronze.

REFERENCES

1 Schliemann, Dr Henry: "Ilios: The City and Country of the Trojans", John Murray, London 1880.

2 Blegen, C.W., Boulter, C.G., Caskey, J.L., Rawson, M. and Sperling, J.: "Troy: Excavations conducted by the University of Cincinnati, 1932-38, 4 vols. Princeton, 1950-58.

3 Blegen, C.W.: "Troy and the Trojans," Thames and Hudson, London, 1963.

TABLE I

Identification and chemical analyses of certified Troy bronzes from Professor C.W. Blegen

Specimen No.	Troy Period	Identification of Location	Description	Chemical Analysis, wt% Cu	Sn	As	Ni	Pb	Fe	Other*	Reference
1	I	--	Mixed with earth	14.94	--	1.98	0.04	--	--	--	A
2	I		Mixed with earth	36.00	--	2.20	0.09	--	--	--	A
37.3	I (early)	Megaron Trench 1-2, Section 2, 3.85 below No.A	Not metallic	15.54	--	1.24	0.10	2.20	--	S	B
37.4	I (early)	Trench 1-2, Section 2-3, 3.00-3.05 below No. B wall		88.51	--	0.89	0.03	Tr	--	S	B
37.5	I	Trench 1-2, 2.00-2.10 below No.B wall	Earthy matter, impregnated with copper								B
3	II			98.8	--	1.1	0.11	--	--	--	A
4	II			98.7	--	1.1	0.18	--	--	--	A
5	II			96.7	2.18	0.97	0.11	--	--	--	A
37.8	II	F4-5, Pit No.4, extension -F95	Nugget	92.15	--	0.19	0.08	0.63	--	--	B
37.9	II (next to last period)	F4-5, the "pit" period (740) MR VIII, p.103	Sheet	96.40	--	1.86	0.18	Tr	--	--	B
37.10	II (next to last period)	F4-5, 715, hole	Rod, little metal, tan oxide	87.8	10.4	0.4	Tr	Tr	1.4	--	B
37.12	II (next to last period)	Below 2nd Street, near skeleton, -F.00	Granules, little metal	88.28	--	1.19	0.02	Tr	--	S	B

TABLE I (Continued)

Specimen No.	Troy Period	Identification of Location	Description	Chemical Analysis wt% Cu	Sn	As	Ni	Pb	Fe	Other*	Reference
37.14	II (last period)	F4-5, 2nd Street, 6.35	Wire 3mm diameter	Silver chloride, no metallic core							B
37.17	II (probably end)	F8, Room 120-740 (burnt layer)	Square wire	96.8	2.4	0.1	0.1	Tr	0.6	--	B
13	III			95.0	2.9	1.5	0.11	0.47	--	--	A
14	III			97.6	--	2.3	0.03	--	--	--	A
37.19	III	F8, Area 110, 610-620	Wire and knob	98.6	Tr	0.8	0.3	--	0.3	--	B
37.20	III	F8, Area 1, - 610		Not analyzed--too corroded							
37.21	III	F8, Area 110, -6.00 MR 7, p.147	Corroded, tan oxide	93.0	5.7	0.8	Tr	0.2	0.3	--	B
37.22	IV	F4-5, -2.90, MR XIII, p.28	Wire	98.5	--	1.0	0.1	--	0.4	--	B
37.23	IV	F8, Area 210, -450, JLC VII, p.13	Wires	97.7	--	2.0	Tr	0.3	--	--	B
37.24	IV - V	F8, Area 2, Under Room 1 of House 204, -4.25, JLC VII, p.25		87.6	11.9	0.1	0.1	0.3	--	--	B
6	V			90.4	9.6	--	--	--	--	--	A
37.25	V	F8, Area 110, -2.90	Very corroded	91.5	--	1.1	Tr	--	--	--	B
7	VI			91.9	8.0	--	0.05	--	--	--	A
15	VI			91.9	8.0	--	0.05	--	--	--	A
16	VI			99.9	Tr	Tr	--	--	--	--	A
37.26	VI	G 2-3, Slope 440-455	Wire	98.7	--	0.3	Tr	--	Tr	--	B

TABLE 1 (Continued)

Specimen No.	Troy Period	Identification of Location	Description	Chemical Analysis wt% Cu	Sn	As	Ni	Pb	Fe	Other*	Reference
37.27	VI	South Gate, 7th Ave., Depth 1.50, N 13, p.1, Vol II	Fragments, green oxide	67.94	9.69	0.22	--	--	--	S	B
37.28	VI	South Gate, 7th Ave., Depth 1.65, NB, p.17, Vol II	Wire	75.86	11.33	0.47	0.04	--	--	S	B
37.29	VI	South Gate, 7th Ave., Depth 1.30, -1.40, NB, pp5-6, Vol III		75.24	11.90	0.63	Tr	--	--	S	B
37.34	VI	EGI, 3.80, -3.90, VI, EP B, p.89		79.16	9.09	0.17	0.02	Tr	--	S	B
37.36	VI	EGI, VI layer, EPB, pp 111,113,119		95.37	--	1.60	0.05	--	--	--	B
8	VI - VII			87.3	11.5	1.2	--	--	--	--	A
9	VII			91.0	9.0	--	--	--	--	--	A
10	VII	E-8, fill "N" of wall		91.2	8.2	0.55	--	--	--	--	A
37.38	VIIa	E-8, fill "N" of wall 11 -350, SLC VII, p.150	Fragment of bronze for analysis	87.7	2.7	0.2	8.9	Tr	0.5	Tr	B
37.42	VIIa	South Gate, 7th Ave., Next to wall, 7R, NB, p.111		79.75	8.5	0.39	0.02	--	--	S	B
37.44	VIII	Under house 8.50, 1.05-95	Fragments of bronze and lead	Too corroded for analysis							B
37.45	VIII	Room 804, +105 -95,DR VIII, p.86									
37.47	VIII	Trench S -5.00-5.10, Cab I, p.142		Too corroded for analysis							

* The letter "S" presumably refers to presence of sulphide in Desch's analyses.

A British Association for the Advancement of Science, C.H. Desch, "Seventh Interim Report on Sumerian Copper", Blackpool, 1936.

B Unpublished chemical analyses conducted by C.H. Desch at N.P.L.

TABLE II. Chronology and Archaeological Details relating to Troy

Period	Date	Significant Details
Early Bronze Age		
Troy I	3000-2500 B C	16 objects of copper, awls, needles, pins, some fragments of corroded copper; also fragments of clay mould casting dagger-blade or spearhead with strengthened midrib. Destroyed by fire, probably due to internal causes.
Troy II	2500-2200	Reconstruction of citadel, encircled by new stone wall, about 2 acres in circuit. Consists of 7 strata (11a - 11g). Palace of Megaron type, increased prosperity, many imports of copper and bronze objects, gold, silver, and lead as well as raw materials. Open and closed moulds of stone (steatite) and clay; several types of crucible are evidence of increased local manufacture. Metal vessels, daggers, leaf-shaped spearheads, knives, single and double-edged, find parallels in Central Anatolia and Aegean region. Schliemann's "treasure" disc. in II g. Destroyed by great fire, probably due to attackers; signs of sudden flight and panic.
Troy III	2200-2050	No break in cultural continuity; survivors rebuilt town and continued local metalworking (2 fragments of crucibles) on a diminished scale. Finds fewer: pins, needles, knife blades with curved point. After 3 or more phases Troy III came to its end; cause not clear.
Troy IV	2050-1900	Schliemann dug through greater part of acropolis of this period. The material from the small undisturbed area, re-excavated by Blegen, is meagre. Only a few objects of metal were recovered: wire pins, a needle, an awl, a few knives. End not known.
Troy V	1900-1800	Improvement in building technique, houses more spacious, built-in furniture. Domed oven (novel feature in IV) developed with fire-boxes and flues. Metal objects few: knife, chisel, pins, and wire. Analyses shows bronze was made and worked. No signs of fire but houses demolished (Indo-European invasion?)

TABLE II (Continued)

Period	Date	Significant Details
Middle and Late Bronze Age		
Troy VI	1800-1300	Major break in continuity, indicating arrival of new people. Free-standing houses, ringed terraces. Citadel becomes powerful strongholds. Bronze more generally used. Horse appears. Bridle bits of bronze, knives, several whetstones of a new type. Mycenean pottery appears in increasing numbers. Destroyed by earthquake.
Troy VIIa	1300-1260	Reconstruction of walls and houses. Relation with Mycenean world maintained. Apparently attacked by invaders. Blegen believes it to be Homer's Troy.
Troy VIIb	1260-1190	Implements and weapons of new types. Few metal and other objects from stratified deposits due to demolition of central part of citadel in Roman times. Only remains to survive on lower edge of acropolis suffered damage from later intrusions. Several bronze implements: double axe, 2 adzes, socketed punch, moulds for socketed axe all resembling Hungarian types; found by Schliemann; all are unstratified but it is probable that they are contemporary with knobbed ware distinctive of T.VIIb[2] and showing great similarity to deposits of L.B.A. in Hungary. Destruction by fire.
Iron Age		
Troy VIII	700 -	Trojan citadel deserted for some 400 years. Revival in 700 B.C., became predominantly Greek colony.

Metallurgical investigation of an iron object of Roman origin from Lower Slaughter, Glos.

ARCHAEOLOGICAL INTRODUCTION Mrs H.E. O'NEIL, F.S.A.

The iron object under discussion, and which may well be an anvil, was found in 1958 at the Romano-British settlement at Lower Slaughter, Glos. It was embedded in ash on a roughly paved stone floor of a small building or hut (site 73), circular in shape with a diameter of c. 13-14 ft. The hut itself was probably of wooden construction and was located only by the extent of its floor, but it lay some 24 ft north of a small building with masonry walls. The walls were faced with a row of large post-holes, indicating uprights to support a verandah to a dwelling house. Coins and pottery associated with the house were of mid to late Roman date A.D.250-400.

The hut, a workshop or forge, was covered with a wide area of deep burning and grey ash. A central large paving stone, 3 ft 2 in long by 2 ft wide, and 6 in thick, had two 2½ in square holes near the centre with two roughly worn slits in the stone opposite them, suggesting that some kind of support with legs had been inserted here for a bench. In the ash were scraps of iron, one which seemed to be part of a horse shoe, while another object was an iron boss, about ½ in diameter, which fitted a bronze stud cap that lay close by. There was no doubt that iron working had been carried on in this hut.

The settlement bordering the Fosse Way between Bourton on the Water and Stow on the Wold was of some size, covering some 20 acres of ground, now gravelled away by Messrs L.J. Farnworth of Stow on the Wold. The work of recording the settlement which covered some 25 years, was rewarded by the finding of many small hut sites, two houses of masonry, eleven wells, ovens (including a corn-drying oven) ditches enclosing small gardens or cattle enclosures, a great quantity of Roman pottery, and many hundreds of Roman coins of the third and fourth centuries A.D.

THE METALLURGICAL INVESTIGATION

G.T. BROWN

The block of iron investigated was irregular in shape and of unknown purpose; tentatively it was classed as an anvil but this is in some doubt. The following findings are somewhat speculative in nature and some opinions are expressed which are not entirely in agreement, metallurgically speaking, with those contained in the published literature.

INVESTIGATING DETAILS

External appearance

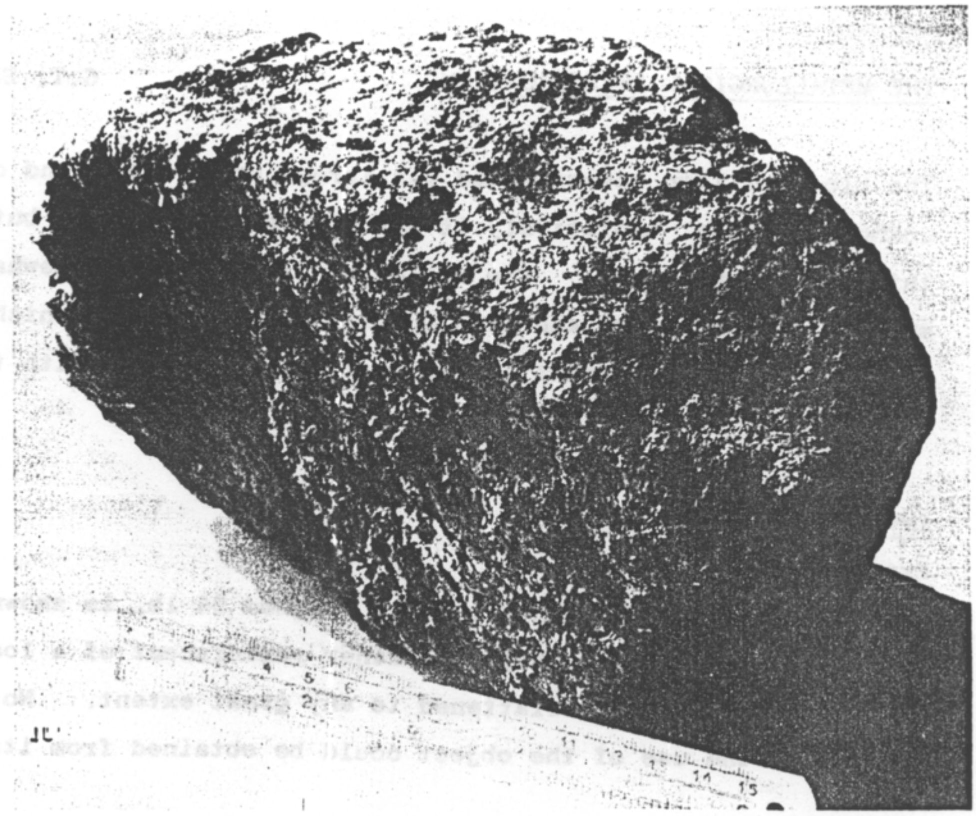
The appearance of the object, which weighed 24 lb, is shown in Figures 1 and 2. The shape is rather reminiscent of a loaf; only one side had been flattened to any great extent. No firm clue as to the use of the object could be obtained from its shape.

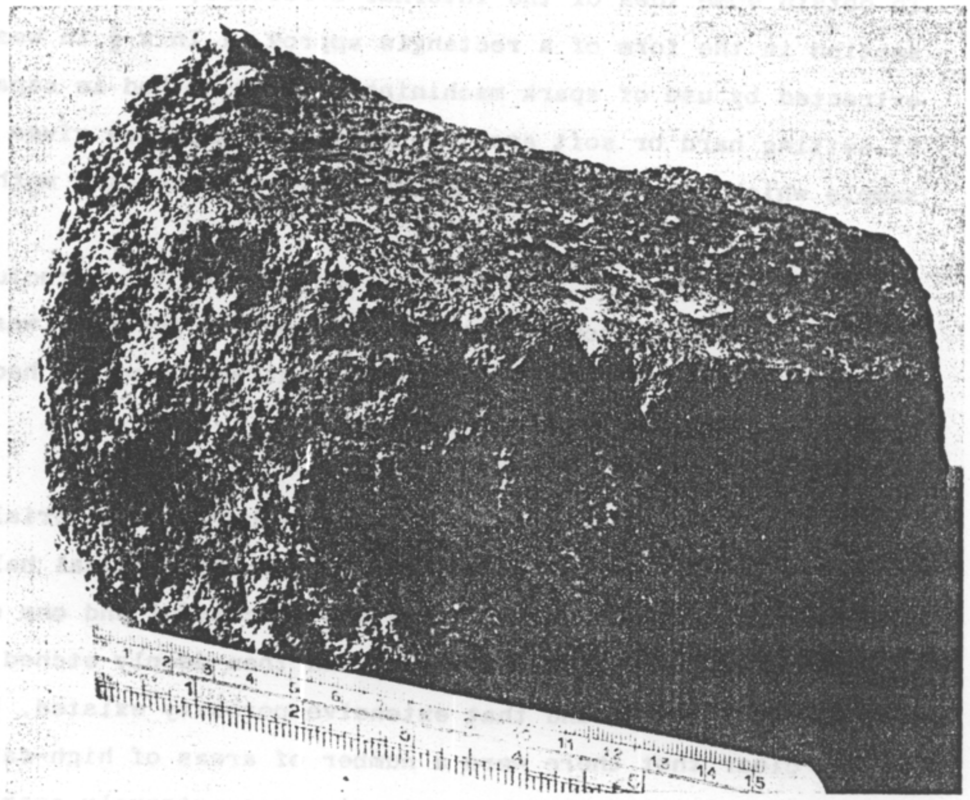
Macrostructure

To obtain some idea of the internal structure, a transverse section in the form of a rectangle approx. 1 in x ½ in was extracted by use of spark machining. This method is capable of cutting hard or soft areas equally well and thus gives a sample which can be used to decide on further cutting methods.

Polishing and etching this section showed that the structure was of very low carbon content and that extensive porosity was present, although the material just below the flattened surface had fewer cavities present than the remainder.

Since there was no evidence of extensive hardened material present, it was decided to cut a complete longitudinal half-section using a power saw. This was successful and one of the cut halves was ground and polished and then deeply etched. Once again it was found that extensive porosity existed, but now it was clear that there were a number of areas of high-carbon material. In general, the grain size was extremely coarse and the centre showed that the original spark-machined piece was typical of most of the iron around it.





Figs.1 and 2 - External appearance of objeot

Figure 3 shows the macrostructure of the half-section, the hole in the centre being where the spark-machined piece was taken. There is no evidence of separate pieces of iron having been joined by forge-welding, nor does the slag appear to have any firm directionality.

Microstructure

One corner of the macro-section was cut off for further polishing and the spark-machined section was also re-prepared.

The structures were examined after etching, and it was found that the material was typical of that produced by the Roman bloomery process, i.e. extremely heterogeneous in character.

Carbon content ranged from virtually nil to that of eutectoid composition (around 0.8%). These variations took place over quite small distances.

Analysis

The spark-machined section was sampled and analysed chemically. The following are the results:

Si	S	P	Mn	N
tr.or nil	0.007%	0.085%	nil or tr.	0.004%

DISCUSSION

From the above results it is clear that the iron object is of bloomery origin. The question is whether it represents a single smelting or is made up of several smaller pieces welded together. Tylecote (1) in examining an anvil came to the conclusion that a similar macrostructure was the result of forge-welding several pieces. In contrast to this, the Corbridge bloom (2) showed much clearer evidence of the separate pieces. In the present case the porosity shows consolidation only near the flat face and it would be expected that if sufficient hot work to eliminate any signs of the boundaries between smaller pieces had been used the general porosity would have been similarly consolidated.

In view of this it seems most likely that this piece of iron was made as a single piece and it is therefore most likely to represent a bloom in an intermediate stage of working. The flat face was the only one that had been forged extensively.

CONCLUSIONS

(1) The material is of the heterogeneous character typical of Roman bloomery iron.

(2) It is most likely to be a single bloom and does not appear to have been made up from smaller pieces.

(3) No clue as to its eventual use can be arrived at from the findings.

REFERENCES

(1) R.F. Tylecote: Trans. Woolhope Naturalist & Field Club, Vol.XXXVII, 1961.

(2) H. Bell et al.: J.I.S.I., 1912, No.1, p.118.

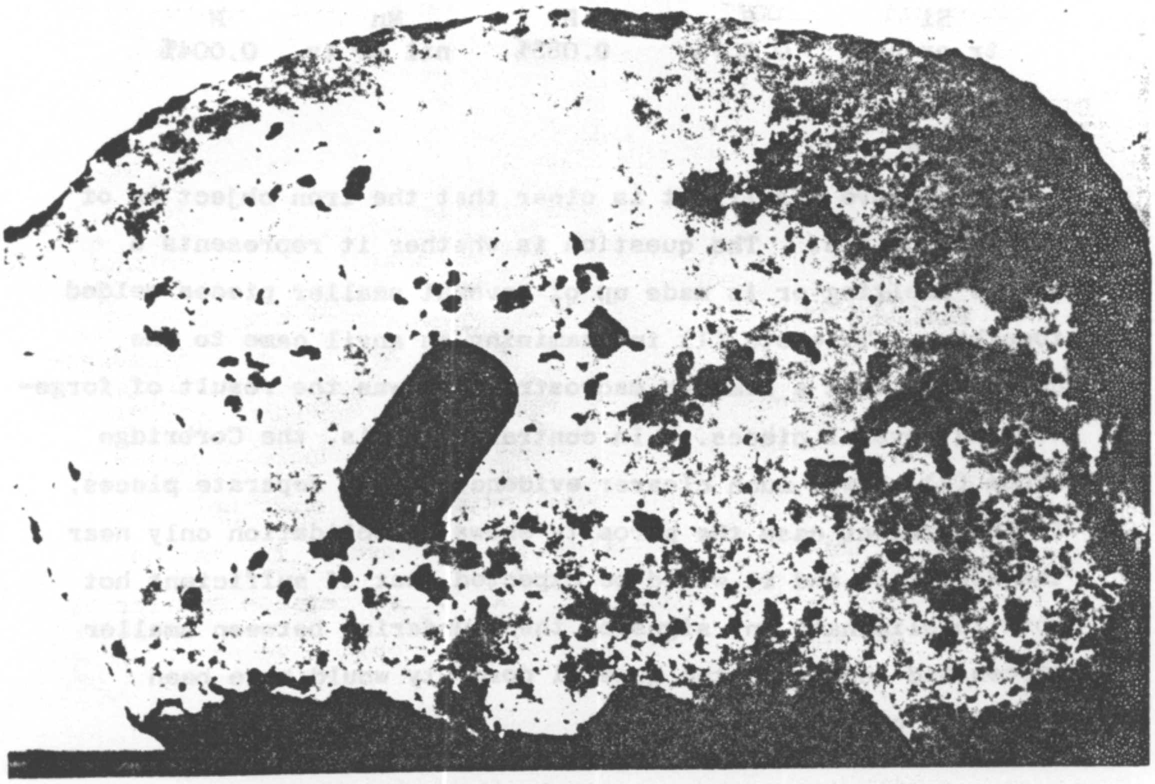


Fig.3 - Macrostructure of section showing porosity

Activities in the Midlands area

CHARLCOT BLAST FURNACE

As a part of the Centenary Celebrations of the Staffordshire Iron and Steel Institute two parties will visit the furnace site, and towards this end a considerable amount of work is in hand. The stack of the furnace is full of an accumulation of many years of farmhouse rubbish, and a fair amount of fallen material lies around the building.

A party of some 15 apprentices from a local steel company is busily engaged on a cleaning out operation, and it is anticipated that the complete interior will be cleared during the next few weeks.

Several interesting points have already been noted. The stack is of square shape, and built of stone blocks and not of clay or marl brick. The square shape appears to have been given some slight ovality, and is in perfect order right down to the bosh area.

A third lintel plate has been uncovered on the fore-hearth side and, although the arch wall between this and the next higher lintel is missing, the surrounding structure is in very good order. Near the furnace a large lump of iron lies partially buried on edge - this was probably the result of a break-out, and a piece has been cut off and taken for analysis and examination.

Preliminary analysis of typical slag samples show some 14 - 15 per cent of lime, which agrees with the documentary evidence that lime was used (Bulletin No.6).

As a result of this work it is anticipated that a major paper can be produced, and the technical aspects compared with the economic considerations published in Bulletin No.6. Attempts to trace the leats to and from the water wheel have been made, and the results are still conjectural.

NORMAN MUTTON

Wolverhampton College of Technology, Industrial History Group.

HALLFIELDS FURNACE, BRADLEY IRONWORKS

The location of the site from the plan of the works set out in the sale catalogue (J.I.S.I. July 1966), which at first was considered difficult, proved to be a comparatively simple matter. A slide was made of the plan, which was then projected on to a modern street map of the area. Magnification was increased until the one thing in common - the Birmingham canal - was in alignment. A visit to the area revealed that the land between Wilkinson Avenue (a significant name) and the canal was still undeveloped, other than for tipping. The area contained the remains of a slag heap and large quantities of pit spoil, and it was evident that, since large quantities of the slag had been removed for building purposes, that which remained represented the material deposited early in the life of the works.

Further verification was obtained from the comparison of the painting by Robert Noyes, (J.I.S.I. July 1966), with the existing landscape, the common feature being the spire of Wednesbury Church.

Two independent surveys, one by the Borough Engineer's department of the Bilston Corporation and the other by the Building and Civil Engineering Department of the Wolverhampton College of Technology, suggested that the actual site of the furnace was under the coal spoil heap. The absence of positive reference points gave rise to a margin of error, and the two surveys varied by some 20 yards.

Exploratory trenches driven through these regions revealed very little, and only pieces of iron ore and coal from the spoil were found. Because of the amount of spoil, this was probably the maximum extent to which exploration by manual digging could be carried out. Fortunately the Owen Organisation showed great interest in the project, and provided a mechanical digger and site engineer. The area originally pegged out was systematically removed down to the original ground level, with negative results, after which the digger moved steadily forward across the whole spoil heap, taking it down to ground level, and re-piling the spoil in the previous tracks.

About 20 yards from the original pegged area and at a depth of some 15 ft, remains of a slag-metalled road were uncovered. Embedded in this road were portions of cast and wrought angle-iron rails (Fig.1); the cast-iron section contained dovetails by which the rails were secured into cast-iron sleepers. Both the cast and the wrought rails contained grooves made by the flat wheels of the bogies which ran over them.

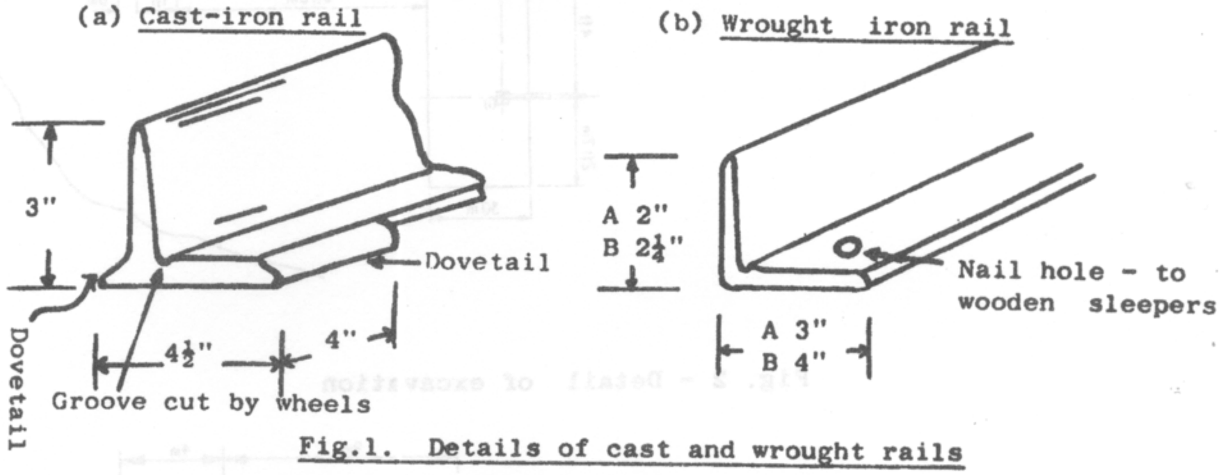


Fig.1. Details of cast and wrought rails

Excavation was continued beyond the edge of the slag roadway, and at a depth of some 15 ft below the roadway (25 - 30 ft below the coal spoil heap) further remains were found. The first to be uncovered was a portion of semi-circular brickwork 2 ft in height; the Noyes painting shows such a wall forming the base of the beehive boilers.

Beyond the wall, foundations of what was probably the bases of the blowing engine and blowing cylinders were uncovered; these are shown in detail in Figs.2 and 3. In order to assist in the discussion of these details it is advisable to add that, since the work being considered was undertaken, a complete inventory of the works (taken in 1846) has been discovered, and many of the details agree with the structures uncovered.

The main foundation (B) appears to be the base of the blowing engine, which was originally located by holding-down bolts at (i) and (ii). The Boulton and Watt Engine Book (J.I.S.I. July 1966) records new engines installed at Bradley in 1779 and 1790, and it was to house one of these larger engines that the extension to this wall and the new holding-down location (iii) was added.

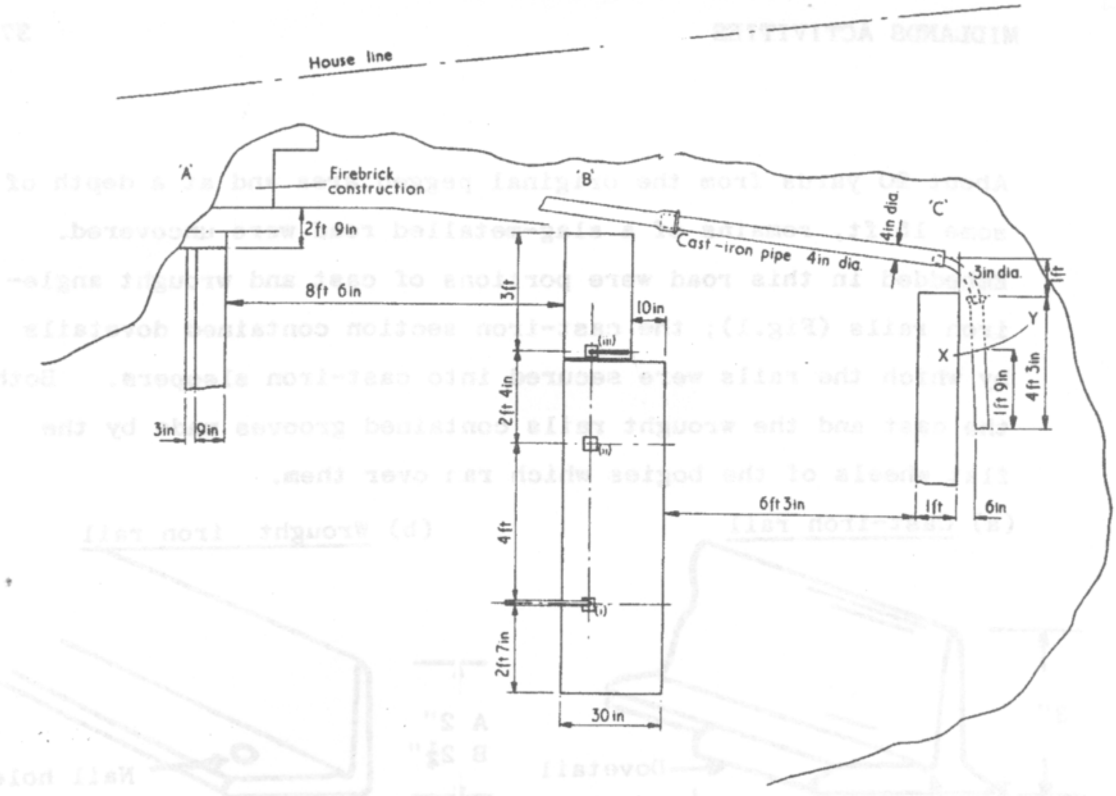


Fig. 2 - Detail of excavation

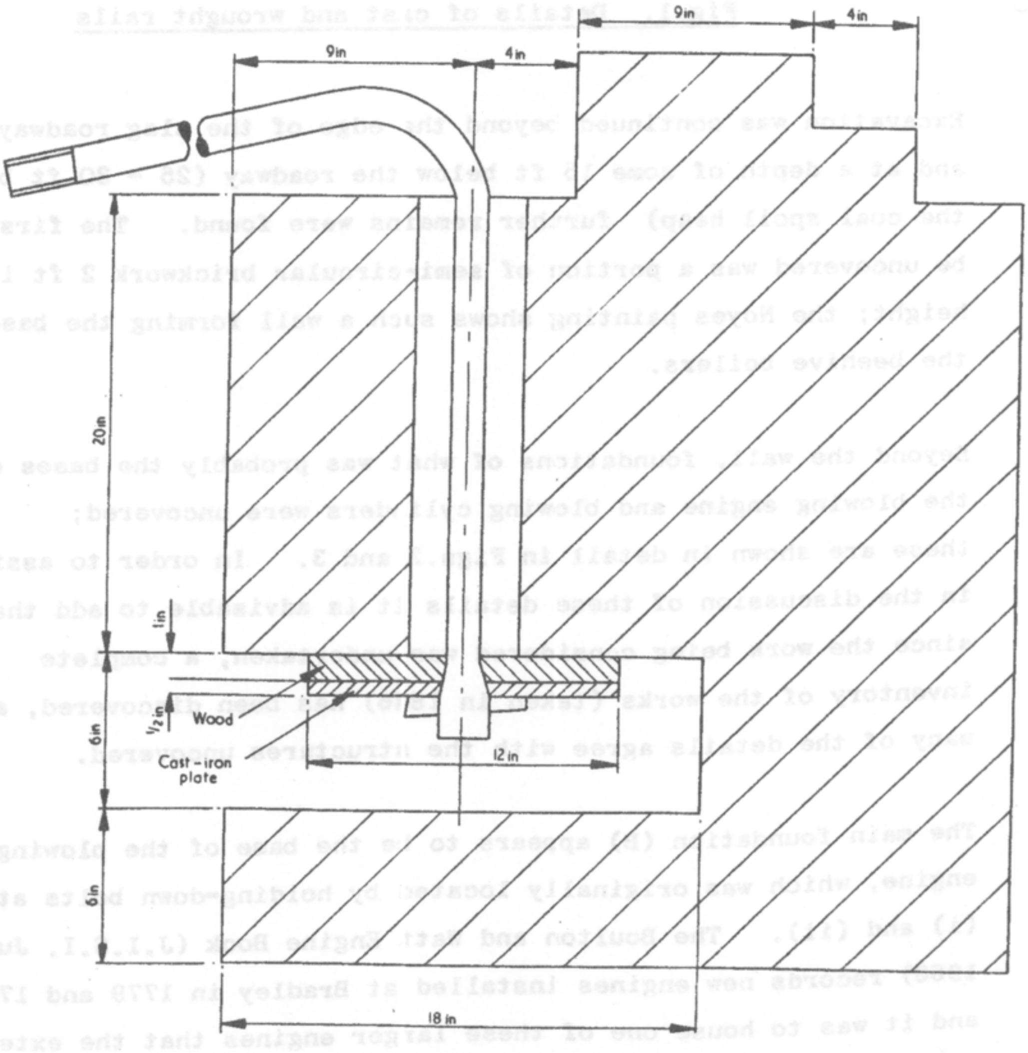


Fig. 3 - Detail of holding-down bolt

The size of these location bolts ($1\frac{1}{4}$in diameter and 6 ft long) agrees with the inventory. The method of securing the lower end of the bolt is of interest; a wrought iron cotter fitted in a punched hole in the lower end of the bolt. This method of securing bolts continued into the present century.

A cast-iron pipe traversing the upper end of the wall is of interest as it represents one of the earliest examples of the method of joining by caulking. The male and female halves are connected and aligned, and hemp or rope wrapped around and arranged to make a seal. Molten lead is then poured into the cavity between the two sections, and this is caulked tight by hammering. This type of joint is in use at the present day. Large quantities of such pipe were used in the works, and the inventory cites one as leading to 'the upper pool'. This pipe was uncovered and rods were pushed into it to determine the extent towards the pond and under the adjoining houses, the rods penetrating for at least 30 ft.

Several other walls and foundations were found, but time did not permit full identification, because it became necessary to infill prior to the return of the excavator.

Further work is proceeding on a documentary basis, and if it is possible to obtain further use of the excavator, another dig will be organised.

W.E. SMITH

on behalf of the Wolverhampton
College of Technology
Industrial History Group.

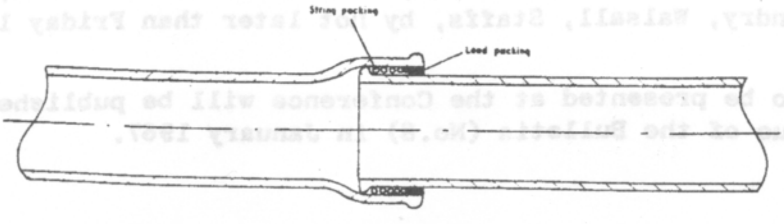


Fig. 4 - Section of jointed pipe

PROGRAMME OF

THE SECOND ANNUAL CONFERENCE

Sheffield

September 1966

The Second Annual Conference is to be held in Sheffield from Friday to Sunday, 9 to 11 September 1966. It has been organised by a local committee under the chairmanship of Mr.K.C.Barraclough.

The full programme of the Conference is as follows :

Friday, 9 Sept.	6.30 pm	Dinner at Sorby Hall, University of Sheffield
	7.30 pm	Introductory remarks by the President
	7.40 pm	Presentation and discussion of the paper : "Derbyshire lead" by Dr R.A. MOTT
	8.45 pm	Presentation and discussion of the paper : "Early copper working in Israel" by Dr. R.F. TYLECOTE (Honorary Secretary)
Saturday, 10 Sept.	8.15 am	Breakfast at Sorby Hall.
	9.30 am	Presentation and discussion of the paper : "Excavations at Rockley" by Mr D.A. CROSSLEY
	10.30 am	Presentation and discussion of the paper : "Abbeydale Works - the historical background" by Mr J.M. BESTALL
	11.30 am	Presentation and discussion of the paper : "The cementation and crucible processes" by Mr K.C. BARRACLOUGH
	12.30 pm	Lunch at Sorby Hall
	1.30 pm	Coach tour of sites of historical interest, including Abbeydale Works, Rockley Furnace, and Wortley Forge.
	6.30 pm	Dinner at Sorby Hall.
	7.30 pm	Informal discussion, based on members' slides and specimens.
Sunday, 11 Sept.	8.15 am	Breakfast at Sorby Hall.
		It is hoped to arrange a morning visit to a Derbyshire lead mine. Should this prove impracticable, there will be a private visit to the Sheffield City Museum.
	1.00 pm	Lunch at Sorby Hall.
		END OF CONFERENCE

Members will by now have received a circular about the Conference, giving details of costs. They are reminded that registration forms should be sent, with the appropriate remittance, to the Honorary Treasurer, Mr M.M. Hallett, Chamberlin and Hill Ltd, Chuckery Foundry, Walsall, Staffs, by not later than Friday 19 August.

The papers to be presented at the Conference will be published in the next issue of the Bulletin (No.8) in January 1967.

Announcements and News

ASSOCIATION WITH THE INSTITUTE OF METALS

It was announced in the last issue of the Bulletin that The Iron and Steel Institute had agreed to provide secretarial and editorial services for the Group, and that members of that Institute could become members of the Group without payment of subscriptions.

The Committee is very pleased to be able to report that The Institute of Metals has agreed to become associated with the Group in the same way, and will be making a contribution towards the cost of secretarial and editorial services. Members of The Institute of Metals will be eligible for membership of the Group without additional payment.

"IRON, STEEL AND THE BLACK COUNTRY"

The Staffordshire Iron and Steel Institute is celebrating the centenary of its foundation in 1966. To commemorate the centenary, a joint meeting is being held with The Iron and Steel Institute (its junior by three years) in the Wolverhampton area from 11 to 14 July.

As part of the centenary celebrations, an exhibition is being arranged at the Bilston College of Further Education under the title "Iron, Steel and the Black Country". The organization of the exhibition has been in the hands of a committee under the chairmanship of Mr G.R. Morton, Chairman of the Historical Metallurgy Group.

The exhibition depicts the development of the industry in the Black Country from early times. It will also show how the industry accommodated the changing pattern enforced upon it by the exhaustion of the supplies of local raw material.

The contribution made by coal, roads, canals, rail transport, and commerce are also considered, and a preview of the industry of the future is included. Thus the exhibition divides itself into four main sections:

1. Early processes.
2. The effects of the industrial revolution
3. The changing pattern
4. The future

Some 27 stands have been arranged, and the co-operation of industry, commerce and education, aided by films of local interest, blends the whole into a continuous story.

The period covered by the 'Early Processes' covers the geology of the area and the raw materials upon which the industry of the district depended for its development. Because of the lack of water on the South Staffordshire Plateau, for the purpose of providing power for water wheels, the early charcoal industry migrated towards the rivers bounding the plateau. The extent of this industry will be illustrated by documentary, descriptive and material evidence of the bloomery process and the later charcoal era. The problem of Dud Dudley and his claims to have successfuly smelted iron ore with raw 'pit coal' are also considered.

In 1766, John Wilkinson introduced the steam engine for the purpose of driving his blowing cylinders. With the establishment of his works at Bradley he released the area from its dependence on water power, and by so doing he brought the Industrial Revolution to the Black Country.

The effects of the Industrial Revolution can be seen by the phenomenal growth of the industry resulting from the work of Wilkinson. In 1863 some 200 blast furnaces were in existence in the Black Country, with 110 in blast using a total of 850,000 tons of ironstone, and making 691,157 tons of pig iron. With the introduction of the puddling process and grooved rolls by Cort, and the later developments by Hall, Staffordshire wrought iron became world famous. Although none is made today, the exhibition will retell the story of its development.

Alongside these advances, a thriving pig and cast iron industry grew. The first casting in iron made in the area was produced in 1561 from the charcoal blast furnace on Cannock Chase, and even until the mid 19th century large castings were made with the metal as-tapped from the blast furnace. The foundry industry is still of major importance in the Black Country.

From these primary industries a multitude of secondary works arose, covering such processes as tube making, nail and chain making, hollow-ware, drop forging and stamping, and many others, most of which are included in stand form.

The influence of transport by road, canal and rail, and the parts played by coal and commerce are also included.

With the exhaustion of the reserves of raw materials, a major reorientation of the industry became necessary, the success of which can be seen in the pattern of the present day.

The exhibition concludes with a glimpse to the future as seen through the eyes of the British Iron and Steel Federation and a large company engaged in the field of nuclear engineering.

The exhibition will be opened by Sir Douglas Bruce-Gardner, President of The Iron and Steel Institute, at 6.0 p.m. on 11 July 1966, and will be open to the general public daily between the hours of 11.00 a.m. to 8.30 p.m.

Refreshments will be available at moderate prices. Special provision and guides will be arranged for parties, including those from schools.

WORK IN PROGRESS

The famous ironmaking settlement of the Roman period at Wilderspool, Warrington, first excavated by Thomas May in the early years of this century, is to be explored further this summer under the direction of Mr F.H. Thompson of the University of Manchester, at the request of the Ministry of Public Building and Works. Mr H.F. Cleere of The Iron and Steel Institute, will be acting as consultant in matters relating to iron working.

Mr.D. Morgan Rees has reported the remains of a 17th century blast-furnace at Woolpitch Wood, Monmouth (SO 487048). These appear to be of a charcoal furnace, built of sandstone, with a square-sectioned shaft, about 24 ft square. The furnace stands near a stream and there is evidence of a bridge connecting the charging platform with higher ground, at which are to be seen the remains of the walls of a building approximately 57 ft long by 20 ft wide. (From "Archaeology in Wales", 1964, p.25).

Mr.Norman Mutton has kindly provided the following notes :

1. Hampton Loade (SO 748864) and Eardington (SO 725897 and 733895), Salop. Forges dating from c. 1777 and in use to 1866 and 1889 respectively as makers of charcoal iron. Papers being prepared on the two related sites and their origins, ownership, and general history up to 1900, on the tinworks at Hampton Loade, which existed from 1822-1826, and on the use of peat in the fineries at Hampton Loade in the 1830s and 1840s, where it replaced part of the charcoal used in the fineries, after preliminary refining (i.e. desiliconization).

2. Upper Arley, Worcs (formerly Staffs). Field work in progress in an attempt to trace the site of an ironworks known only from an auction notice of 1807.

3. The Hurst, Morville, Salop. (SO 671959). Site of a 17th century blast furnace, well known to local historians but not in Schubert's list, has had a preliminary inspection. The site is overgrown, but the furnace appears to have been built right up to the downstream face of the lowest dam; there is extensive evidence of charcoal storage and burning in the adjacent field.

4. Lower Norncott, parish of Stoke St Milborough, Salop (SO568867). Site of a 17th century blast furnace, brought to NM's attention by Trevor Rowley, Area Adult Education Tutor for S.E. Shropshire, who found a map reference of about 1694. It is not in Schubert's list. The site is partly overgrown, with slight masonry remains. To be surveyed (and perhaps excavated) this summer.

The Honorary Secretary (Dr R.F. Tylecote) is proposing to excavate the 17th century bloomery site at Muncaster Head, Cumberland, in July next year (1967). Those interested in assisting on this excavation should write to him at the Department of Metallurgy, University of Newcastle upon Tyne. He would particularly like to hear from those with previous excavating experience, especially in the fields of recording and drawing.

CARBON-14 DATING OF IRON

The following article is reprinted from Current Anthropology, Vol.6, No.4, October 1965. It was sent by the author, Dr. Nikolaas J. van der Merwe of Yale University, who would like to hear from anyone who could let him have further iron specimens for analysis.

The calibration of a method for the carbon-14 dating of iron and the successful dating of an iron sample of known age by the carbon-14 method has provided the archaeologist with a valuable new tool for age determination. Research on the application of the method to the dating of iron objects, first reported in CA 4:375-76, is being carried out at the Yale Radiocarbon Laboratory.* The carbon-14 method of age determination, which commonly measures the radiogenic component of carbon in organic samples by means of gas-counting techniques, has recently been used in the investigation of cosmic-ray-induced carbon-14 in meteorites (Goel and Kohman 1962; Suess and Wänke 1962), and it has been suggested (Turekian 1961) that the method also be applied to the dating of iron objects of archaeological interest. Date of manufacture can be ascertained by measuring the radioactivity of the carbon dissolved and occluded in the metal in the process of smelting. In the case of cast iron the carbonization is intentional, and the alloy may contain as much as 5% carbon. When wrought iron is beaten out, most of the carbon is removed, but unsophisticated methods usually prove insufficient to remove all the occluded carbon from the manufactured product. In primitive smelting furnaces charcoal was commonly used as the smelting agent; this process can still be observed today in many parts of the world. With the advent of the industrial revolution, coke replaced charcoal as the smelting agent most commonly used; in England, for example, foundries started converting to coke smelting around 1700, while charcoal continued to be used in the U.S. until the 19th century. Since coke contained no carbon -14, iron made with this type of fuel is not directly datable. The transition from charcoal to coke as a smelting agent is well-documented in most areas, however, and presents no serious problem to the archaeologist.

Accurate dating required a minimum carbon content of 1 gram, 5 grams being preferable. Cast iron samples of 100 grams or more allow for incomplete carbon extraction in the laboratory and give the best results. Carbon is extracted from the samples in the form of carbon-dioxide through direct combustion at high temperatures (see CA 4:376). Excess oxygen and the fine dust of iron oxides are removed from the gas in preliminary cleaning steps. For further cleaning, the laboratory's standard gas-purification system is used to remove traces of sulphur oxides

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* The contributions of Minze Stuiver, Director of the Yale Radiocarbon Laboratory, to the research reported here are gratefully acknowledged. The project is supported by a grant from the National Science Foundation (GS-281).

and similar products of the combustion process. The carbon -14 activity of the purified gas is measured in a proportional gas counter. The results are compared with a modern standard to establish the carbon -14 age of the sample.

To determine the accuracy of this procedure and the possible effects of corrosion, samples of modern, coke-smelted cast iron were used. Theoretically, no carbon-14 activity is expected in such samples, except for an unknown amount of contamination which is likely to be introduced at the foundry. A corroded, uncleaned sample (Y-1503) showed 1.2 ± 0.2% radioactivity, relative to a modern standard. In terms of the duration of the Iron Age, this result represents an error of about 100 years. A 2nd sample (Y-1502) was leached with acetic acid before milling and showed 1.3 ± 0.3% radioactivity, thus ruling out this method of cleaning. A 3rd sample (Y-1501) was thoroughly cleaned through grinding, dry peening, and acid leaching. This sample showed 0.7 ± 0.2% radioactivity, representing an error of about 50 years for the Iron Age.

In an actual age determination, an iron sample (Y-1504) from Saugus, Massachusetts, with a known date of manufacture of 1650 ± 50 A.D. was cleaned by the same method and yielded a carbon-14 date of 1600 ± 60 A.D. Further experiments are now under way to determine the increased accuracy which may result from baking out the sample to remove adsorbed atmospheric carbon-dioxide.

Although increased accuracy is possible, the results obtained are within the range of statistical error of the standard carbon-14 dating method. By adding bake-out procedures, it is expected that carbon-14 dates for iron samples will be more consistently accurate than dates for organic materials. The carbon in an iron object is sealed in a sterile environment at the time of manufacture and is subject to far fewer sources of contamination than, say, charcoal buried in the ground. With the additional advantage that iron is usually more abundant than charcoal in Iron Age sites, this method of dating should have considerable appeal for archaeologists who are interested in this period of man's history.

References

GOEL, P.S. and T.P. KOHMAN. 1962. Cosmogenic carbon-14 in meteorites and terrestrial ages of 'finds' and craters. Science 136:875-76.

SUESS, H.E. and H. WÄNKE. 1962. Radio-carbon content and terrestrial age of twelve stony meteorites and one iron meteorite. Geochimica et Cosmochimica 26:475-80.

TUREKIAN, K.K. 1961. The role of trace-element geochemistry in archaeology. Yale Scientific Magazine 35(4).

EARLY GOLDSMITHS' TECHNIQUES

An exhibition of Viking Age gold and silver artefacts was recently held at the British Museum, when some of the master-pieces of the early Scandinavian goldsmiths were on display.

A handbook was prepared for the exhibition by Historiska Museet, Stockholm, which dealt with the objects on display in terms of technique rather than the normal chronological treatment. The booklet forms an admirable summary of early techniques for the shaping and forming of precious metals. Copies are still on sale at the British Museum bookstall, price 5/- each.

HISTORY OF THE BLACK COUNTRY IRON INDUSTRY

In connection with the centenary of the Staffordshire Iron and Steel Institute, referred to above, The Iron and Steel Institute is publishing 'The Black Country Iron Industry - A Technical History', by W.K.V. Gale, President of the Newcomen Society and a member of the Group. Copies may be obtained from the Institute, price £4.

BACK NUMBERS OF THE BULLETIN

A limited number of back numbers of the Bulletin are available. Copies may be obtained from Mr H.F. Cleere, The Iron and Steel Institute, 4 Grosvenor Gardens, London S.W.1, price 5/-each.

Abstracts

By arrangement with the Editor of the Journal of The Iron and Steel Institute, abstracts of papers of historical interest originally published in the Abstracts section of that Journal are being reprinted in the Bulletin, together with certain other abstracts prepared by members of the Group.

BRITISH ISLES

The development of iron smelting techniques in Great Britain R.F. Tylecote (Organon, 1965, 156-178). A brief survey of iron smelting in Britain from the Iron Age to the 18th century, based on the most recent evidence from excavations and surveys.

A metallurgical history of the Valley of the Wye T.G. Grey-Davies (Metallurgia, 1965, 72, Oct.,153-158). The metallurgical history is given of the region from Roman times, with particular reference to wire production in the Tintern district.

Sir Henry Sydney's steelworks E.N. Simons (Brit.Steel, 1965, 31, Sept., 296-297). About the middle of the 16th century the activities of the Robertsbridge ironworks were extended by Sir Henry Sydney, Edward Roberts and other partners to make steel. Forges were erected with the advice of experienced steelmakers from the Westphalian district of Germany. The new steelworks flourished at first, but was soon out of business because of price cutting in Germany, Sweden and Russia.

The use of peat in the extraction of iron from its ores G.R. Morton (Iron Steel, 1965, 38, Aug., 421-424). An account is given of the use of peat for smelting iron at Leighton furnace in the parish of Wharton, near Lancaster, in the early part of the eighteenth century.

A famous eighteenth-century Shropshire foundry - contemporary plan reveals layout (Found.Trade J., 1965, 119, Sept.9, 337-338). Notes on the 18th Century Madeley Wood Ironworks, based on tracings of the original plans, are presented.

Billingsley Furnace N.Mutton (Steel Times, 1966, 192, Feb.25, 249-250). A brief history is given of the blast furnace built to satisfy the demand for iron for armaments during the Napoleonic Wars (1793-1815). At Billingsley, coal occurred naturally in association with iron ore, and all the required raw materials were available nearby. A profitable industry was thus operating which was, however, forced to close down at the end of the war.

Final blaze of glory for Crumlin Viaduct (Steel Times, 1965, 191, Sept.17, 363-364). Crumlin Viaduct, of wrought and cast iron, situated in the Western Valley of Monmouthshire and regarded by many as a masterpiece of engineering skill, is to be demolished. Recently several scenes for a film have been shot at Crumlin, so that the viaduct is destined to end its days, as it started in 1857, in a blaze of glory.

Redundant masterpiece (Brit. Steel, 1965, 31, Sept.,295) The Lydbrook viaduct was erected in 1872-4 to connect the coal mines of the Forest of Dean with the towns of the Wye Valley. This note refers to the recent demolition of the sandstone and wrought iron structure and to the formation of Richard Thomas and Company at Lydbrook about the time that the viaduct was built.

EUROPE

Old industrial works in Norway G. Thuesen (Tech. Ukebl.,1966, 113, (3), Jan. 20, 33-37). (In Norw.) A survey of the remains of ironworks and other factories.

An ancient Polish steel-making centre J. Zimny (Hutnik, 1965, 32, (3), 69-76) (In Pol.) About 5000 sites of ancient bloomeries have been found in Gory Swietokrzyskie which produced about 8500 t of iron and 32000 t of slag during the first four centuries of our era.

A history of Polish iron ore mining T. Szreter (Problemy Projektowe, 1965, 13, (8), 245-253) (In Pol.). The earliest workings date from the Hallstatt period and were situated on and about the river Odra. During the La Tène period these workings spread further eastwards, reaching the rivers Wzrta and Vistula. During Roman times the area of these workings had trebled, reaching the rivers Notec and Prosna. In the early Middle Ages a deposit of magnetite was discovered at Kowary. Between the 14th and 17th centuries numerous bloomeries were established using limonite, siderite and other ores. In 1815 the number of siderite workings was 321 and those of limonite 132, supplying ore to 63 existing iron-making furnaces. Between 1870 and 1910 the production of iron ore, with the exception of the Czestochowa workings, was in decline.

The first coke blast furnace in Germany, in particular in the Rhineland and Westphalia I. Lange-Kothe (Stahl Eisen, 1965, 85, Aug.26, 1053-1061) (In Ger.) An evaluation of the literature and especially of the records in the West German State archives on the introduction of coke to the German iron industry is made. A correction of a former view is made to give a new series of dates for the commencement of melting with coke in the Rhineland and Westphalia.

Investigations on materials and slags from prehistoric bloomery furnaces in Bohemia and Moravia M. Bartuška and R. Pleiner (Techn. Beiträge zur. Arch., 2, Mainz, 1965). Survey of furnace types and construction and slags, with analyses and photomicrographs of structures.

ASIA

Asia Minor - country of origin of iron? Report on excavations in Commagene F.K. Dörner (Stahl Eisen, 1966, 86, Jan.13, 1.-7) (In Ger.).

AMERICA

America's iron backbone - an historical note T.R. Counselman (Min.Eng.,1965, 17, July, 152-156) The development of the iron ore industry in USA is examined briefly.

METALLURGICAL INVESTIGATIONS

Metallurgical investigation of some iron blooms of the Roman era found on the Lower Rhine G. Becker and W. Dick (Arch. Eisenh., 1965, 36, Aug., 537-542) (In Ger.) The history of the finds and their special interest for ferrous metallurgists are discussed. Reports and investigations of the iron blooms are made with their chemical analysis, microstructure, and technological properties. Slag investigations are also reported.

Examination of the blades of La Tène iron swords E.H. Schulz and R. Pleiner. (Techn. Beiträge zur Arch., 2, Mainz, 1965). Results of metallographic examination of six La Tène period swords from Germany, Hungary, and Jugoslavia.

PROCESSES

The art of steelmaking, XI R. Groves (Can. Min. J., 1965, 86, July, 58-60) Another instalment of a history of steelmaking in Britain from pre-Roman times up to the tenth century.

Developments of Bessemer's process 100 years ago M. Schofield (Steel Times, 1965, 191, Aug.13, 215-216) The installation in 1865 of the first successful Bessemer steel plant in USA by Alexander Lyman Holley is noted. Holley had acquired American rights to Bessemer's patent, but had to face strong opposition from William Kelly, who claimed to have invented an air-blowing process.

Rolling of iron W.K.V. Gale (Edgar Allen News, 1965, 44, Oct., 231-233) An illustrated historical account of techniques used in the rolling of wrought iron.

Contributions to the history of tinplate production A. Lück. (Stahl Eisen, 1965, 26, 1743-1751). A survey of tinplate production from early attempts at tinning in the Middle Ages to recent times.

BIOGRAPHY

Eminent Metallurgist and Chemist M. Schofield (Metallurgia, 1966, 73, Feb., 64-66) An outline of the life and work of Sir Isaac Lowthian Bell. His work in developing the chemical industry on Tyneside and in producing aluminium cheaply from its ores is described, together with his work in the iron industry involving the development of larger blast furnaces and the use of Cleveland ore.

The Historical Metallurgy Society was established in 1962, to record and encourage the preservation of early iron blast furnaces in the United Kingdom. Its scope now covers all aspects of metallurgical history and has an international membership which includes members from Africa, Asia, Australia, Europe and North America. Ferrous and non-ferrous interests are equally represented.

From April 1963, the Society published results of its research at regular intervals. Since January 1967, it has produced an annual Journal (originally called Bulletin) issued in two parts, in the Spring and the Autumn, totalling some hundred pages with a digest of abstracts collected from world-wide sources. This is edited by Professor Ronald Tylecote of London University's Institute of Archaeology whilst the abstracts are collated by Dr Paul Craddock from the British Museum Research Laboratory. Occasional Papers are also published and in the past have included *Sydney Gilchrist Thomas and Blaenavon*, to mark the centenary of the Gilchrist/Thomas basic-steel process and a survey of 19th-century blast furnaces in Sweden, edited by Dr Marie Nisser and produced in conjunction with Jernkontorets Bergshistoriska Utskott of Stockholm.