HISTORICAL METALLURGY

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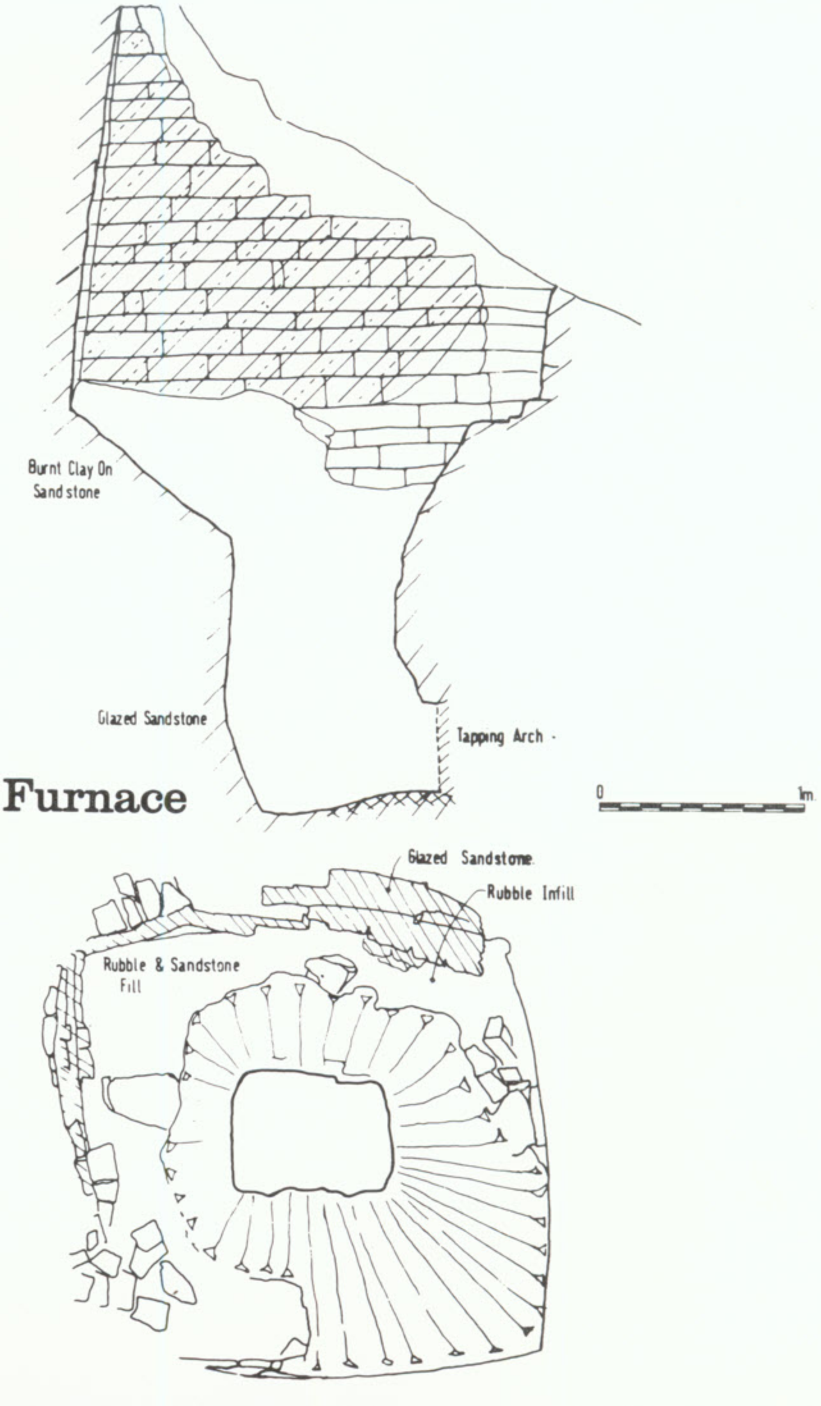
Allensford Furnace



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Ethiopian Bloomery Iron and the significance of inclusion analysis in iron studies

J A Todd and J A Charles

Introduction

In recent years several ethnographic accounts of bloomery processes have been published, as have some detailed examinations of individual iron objects and, less frequently, papers concerning the determination of provenance of iron objects. Many of these reports do not, however, contain the maximum information it is possible to obtain with modern metallographic and microanalytical techniques. The present work attempts to combine these three topics in a full study of one of the few remaining primitive bloomery processes still practiced today, in Ethiopia.

The main advance in relating iron objects to ore sources has been achieved by purposeful concentration on non-metallic inclusion analysis by electron probe – first proposed in 1972,[1] and used throughout this research. Previously Haldane[2] stated that 'there is a high probability that a relationship exists between the trace-element composition and the provenance of ironwork from the Late Pre-Roman Iron Age of Somerset'. By 'trace-element' composition he refers to an analysis range of 0.003 – 0.1wt% and he draws his conclusions from analysis for the following elements in the iron as a whole: calcium, magnesium, titanium, lead, copper, nickel, manganese and copper. At the temperatures operating in the pre-industrial furnace, the majority of associated gangue minerals in the ore, (such as lime, magnesia, silica, alumina) are not reduced into the iron. They form slag phases which remain entrapped in the iron and which constitute a major heterogeneity.

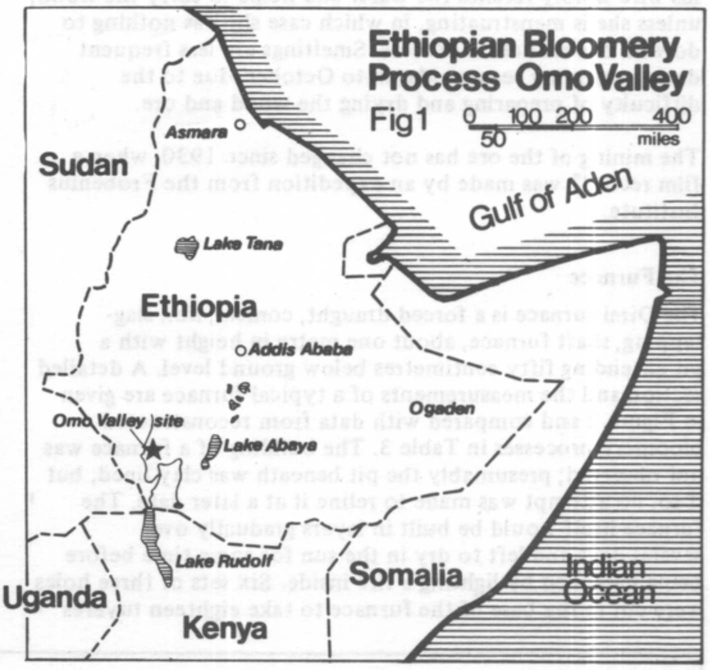
It is, therefore, possible that the contents of calcium, magnesium and titanium quoted in Haldane's work arise from the heterogeneous distribution of slag phases trapped in the iron object but not separated in analysis. From thermodynamic considerations as reflected in the Ellingham[3] oxygen potential diagram, it is equally clear that elements such as phosphorus, nickel, copper and arsenic can be reduced into the iron.

We believe that the most satisfactory method of relating objects to ore sources will be achieved by focussing attention on the 'non-metallic' inclusions found in all samples of ancient ancient iron. They contain much of the unreduced gangue material associated with the ore, and it has been found that meaningful conclusions can be drawn by comparing analyses of the minor elements present in both ore and slag, rather than resorting to more complex trace element analyses, where there are greater sources of error arising from the analysis at very low overall concentrations and the heterogeneity in relation to sampling. Complications arise if flux has been added to reduce the free running temperature of the slag and the contribution of charcoal ash has always to be considered. These will be discussed in a later section.

It is hoped that the structure of this paper will provide a means of answering Professor Piaskowski's call[4] for some standardisation of the form of metallurgical reports. The results are here presented in two sections: the first contains a detailed description of the Ethiopian bloomery process for comparison with both ethnographic data and reconstructed bloomery processes, and the second gives full details of the metallurgical examination of the ore, furnace products and finished artefacts, with analyses.

The Ethiopian Bloomery Process

Fieldwork took place in 1973 among the Dimi of Gemu Gofa Province, S W Ethiopia, who inhabit a mountain range in the northern part of the Omo Valley (Figure 1). At that time there were about forty adult smiths still working in Dimam, mainly during the dry season. The manufacture of iron represents an important local industry, supplying most of the agricultural tools, weapons and ritual objects used by the Dimi and their immediate neighbours, the Bodi.



Scrap metal is not imported because of the difficulties of transport – mules crossing the lowland plane die, probably from triapanosomiasis (carried by tsetse fly) – and the distance from the air strip (approximately seventy miles) is too great to carry iron as head loads. Further ethnographic details concerning blacksmiths and the ritual significance of iron can be found in J A Todd[5] (1976) and D M Todd[6] (1975).

Preparation of Ore and Fuel

The main ore used for smelting was limonite ($Fe_2O_3.2H_2O$), but magnetite was also smelted. Spectrographic and chemical analyses of the Ethiopian ore are given in Tables 1 and 2 – sample 02 contained a large proportion of magnetite and 04 a lesser amount. The ore occurs as surface outcrops and is extracted from the surface or from small pits with digging sticks and hoes. It was reported that fire setting had to be used to break up the magnetite ore. Limonite was smelted on its own, but the magnetite was mixed with limonite. The ore was crushed at the site of extraction, using stones; unwanted material was hand sorted and the ore was left to dry in the sun. Sample 05 is an example of an unsorted ore. No washing of ore or roasting process was observed or reported. The ore was crushed approximately to cubes of side length half an inch. Some slag from the discard of previous reductions, selected by its higher density, was added to the ore There were no taboos associated with the digging of ore. Most Dimi knew which was good ore and would prepare both ore and charcoal and operate the furnace bellows if necessary. Recent tribal warfare with the Bodi has hindered ore collection as several ore sources lie in Bodi territory. Expeditions to these areas have become less frequent, particularly as the smiths no longer dare travel alone.

Charcoal is prepared from 'singl' wood, three large trees being required to make sufficient charcoal for one smelt. The mountain range is densely forested and terraced, and each year terraces are cleared for farming. The trees are left in the fields for several months to dry out and collection presents no difficulties; the problem of deforestation does not arise because of the small scale of the industry. The wood is piled, burned, quenched, broken into pieces about one inch cube and stored in grass bundles. The smith prepares the charcoal, his wife simply fetches the water and helps to carry the wood, unless she is menstruating, in which case she has nothing to do with the reduction process. Smeltings are less frequent during the rainy season, March to October, due to the difficulty of preparing and drying the wood and ore.

The mining of the ore has not changed since 1930, when a film record7 was made by an expedition from the Frobenius Institute.

The Furnace

The Dimi furnace is a forced draught, conical, non slag-tapping, shaft furnace, about one metre in height with a pit extending fifty centimetres below ground level. A detailed section and the measurements of a typical furnace are given in Figure 2 and compared with data from reconstructed bloomery processes in Table 3. The building of a furnace was not observed; presumably the pit beneath was clay lined, but if so, no attempt was made to reline it at a later date. The furnace itself would be built in layers gradually over several days and left to dry in the sun for some time before being hardened by lighting a fire inside. Six sets of three holes were cut in the base of the furnace to take eighteen tuyeres which link to six bowl bellows. The tuyeres consist of a two pipe arrangement, making a total of thirty six pipes, the larger pipes being sealed with clay into the base of the furnace, whilst the smaller pipes are sealed to holes on the outside of the bellows pots. This arrangement is shown in Figure 3. The small pipes did not protrude into the bellows pot; their internal diameters were the same as those of the outlet holes

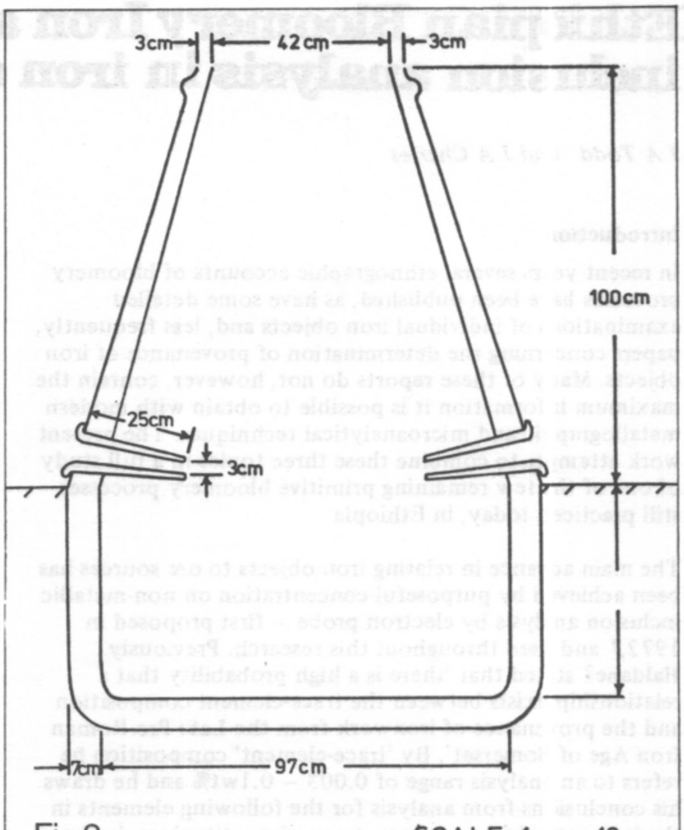


Fig 2 SCALE 1cm=10cm

Scale drawing of the Dimi furnace.

TABLE 1

Spectrographic analyses of Ethiopian Ores and Slags

Element	01	02	03	04	05	06	S1	S2	S3	S4
Cu	tr+	tr+	tr+	tr+	tr+	tr+	tr+	tr	tr	tr+
Sn	tr	tr	tr	tr	tr	tr	tr–	nd	nd	tr+
Ti	tr–	tr–	tr–	tr–	tr–	tr–	tr	m	tr	tr
Zn	tr	tr	tr	tr–	tr	tr	tr–	nd	tr–	tr–
Na	nd	nd	nd	nd	m	nd	tr	nd	nd	tr
Ni	tr	tr	tr	tr	tr	tr	tr	nd	nd	tr
Co	nd	nd	nd	nd	nd	nd	tr	nd	nd	tr
Ca	nd	nd	nd	nd	nd	nd	tr	tr	nd	tr
Mo	tr	tr	tr–	tr–	nd	nd	tr	nd	nd	tr
Al	m	m	m	m	m	m	m	m	m	m
Fe	M	M	M	M	M	M	M	M	M	M
Si	M	M	M	M	M+	M	M	M	M	M
Mg	m	m	m	m	m	m	m	m	m	m
Mn	m	m	m	m	m	m	m	m	m	m
Bo	nd	nd	nd	nd	nd	nd	nd	nd	nd	tr

M = major, m = minor, tr = trace, nd = not detected.
The following elements were not detected: Ag, V, B, As,Cr, Pb, Sb.

in the bellows pot. It should be noted that the small pipes rested on, but did not fit tightly to, the large pipes, so that when the furnace was in operation, some of the excess pressure was initially released by flames shooting out of the base of the furnace. This arrangement also prevented flame and heated air from being drawn into the pot and burning the operators' hands. The tuyeres were not permanent fixtures and the pipes were removed immediately the operation of the bellows ceased, so that they could be kept for re-use instead of fusing with the solidifying slag. Once the reduction was under way the tuyeres had to be cleared of slag continually with green wood. Tuyeres were formed by moulding clay around a smooth stick and drying in the sun and they were not separately fired before use.

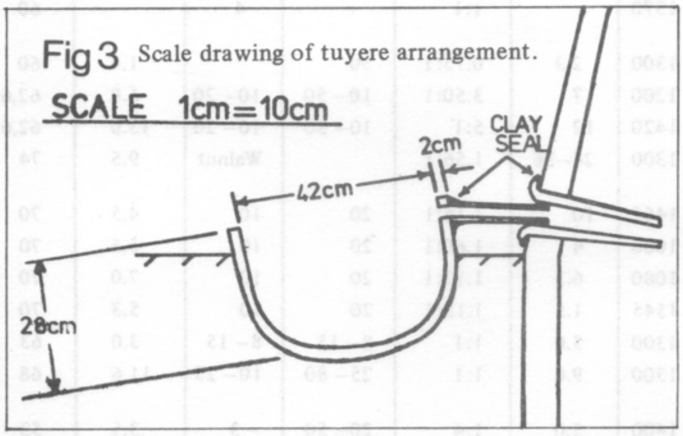


Fig 3 Scale drawing of tuyere arrangement.

The bellows pot was a clay bowl set into the ground and sun dried. The diaphragm, which was not a permanent fixture, consisted of a goat or sheet skin tied onto the bowl, with local rope, with its smooth side uppermost, (ie. the hair was not removed). The centre of each skin contained a hole which acted as a valve. It was operated by inserting the thumbs in the hole and raising the skin to admit air, then closing the hole with the palm of the hand to force the air into the furnace. The average blowing rate was forty-seven per minute, to a rhythm called by the leading smith, but was increased to sixty per minute for short periods after the addition of fuel and charcoal. Drum bellows in which the hole in the diaphragm acts as a valve are distributed in the North and North East of Africa and Cline[8] (p.102) has suggested that this form is a hybrid derived from the open bag bellows (characteristic of India, South Arabia, Horn of Africa and the Sahara) and the closed drum bellows.

The furnace was not destroyed after each operation as the bloom was removed through the top. The furnace which was studied had cracked during previous smelts and had been repaired by sealing the gaps with fresh clay several days before use. Reinforcing vines were also tied round the top. Similarly the bellows pots were also repaired on the day of operation (Figure 4).

An Example of a Timed Dimi Smelt

The blacksmith started work at 3.30 pm after the main heat of the day. The ore formed a pile approximately one foot high and two and a half feet in diameter, and included slag from a previous smelt. Six bundles of charcoal had been prepared and the grass from these bundles was used to start the fire.

3.30pm The furnace was packed solidly with dried grass. Water had been placed in the bellows pots earlier but most had evaporated.

3.45pm Fire was brought and the grass lit through the holes in the bottom of the furnace. It was allowed to burn for a few minutes and then four scoops (ie. four hollow tree trunk sections) of charcoal were added.

3.55pm The large clay pipes, which had been made earlier in the week were placed by each bellows pot.

TABLE 2

Chemical analysis of Ethiopian Ores

	01 **Chalco**	**02** **Gerfa**	**03** **Gerfa**	**04** **Garo**	**05** **Wocho**	**06** **Balcha**
Fe_20_3	68.67	75.37	77.37	55.79	8.53	53.40
$Si0_2$	6.70	7.10	6.70	17.71	63.92	12.30
Mn0	3.43	2.06	–	–	–	3.70
Al_20_3	5.75	7.42	1.29	11.18	18.31	8.20
Ca0	nd	nd	nd	nd	nd	0.50
Mg0	nd	nd	nd	nd	nd	tr
% moisture loss	2.49	2.18	2.52	3.35	10.08	–
% combined H_20, $C0_2$	12.12	3.10	11.72	10.77	3.40	–
P_20_5	0.73	2.05	0.27	0.64	tr	0.97
S	<0.01	0.01	<0.01	<0.01	<0.01	<0.10
$Ti0_2$	–	–	–	–	–	2.5
Total	99.90	99.29	99.88	99.45	104.25	
$\frac{Ca0}{Si0_2}$						0.041

All analyses in the above and following Tables are given in weight percent.

TABLE 3

Results of emperimental work on bloomery furnaces*

Furnace type	Date	Internal diameter m	Stock height above tuyere m	Air l/min	No.of tuyeres	Air rate l/min /cm^2	Max temp ^{o}C	Time to process h	Charcoal to ore ratio	Charcoal size mm	Ore size mm	Burning rate kg/h	Ref
Bowl	BC	0.22	0.30	71	1	0.18	1250	6	3:1	– 6	– 12	0.8	67
Jutland	300–500AD	0.43	1.00	ind'd	4		1270	4	2:1	–100	–6	5.0	54
Polish	200–400AD	0.49	0.44	320	2	0.17	1300	9	1:1		–4	8.7	58 59
Czech Lodenice	200–400AD	0.26	0.50	320	1	0.60	1370		1:1		–4		60
Novgorod	Med	0.30	0.79		1		1300	2.3	0.75:1	50		1.8	60
Noric I	EIA-R	0.46	1.00	160	1	0.096	1200	7	3.50:1	10– 50	10– 20	6.8	62,61
Noric II	EIA-R	0.76	1.50	320	1	0.06	1420	12	5:1	10– 50	10– 20	13.0	62,61
Siegerland	400–200BC	0.97	1.60	ind'd	1		1300	24–36	1.56:1		Walnut	9.5	74
Czech	Slav	0.20	0.80	210	1	0.65	1465	10	1.16:1	20	10	4.5	70
Czech	Slav	0.20	0.80	270	1	0.86	1080	4	1.60:1	20	10	5.5	70
Czech	Slav	0.20	0.80	270	1	0.86	1080	6.3	1.12:1	20	10	7.0	70
Scharmbeck	R	0.27	0.78	210	1	0.45	1545	1.5	1.15:1	20	10	5.3	70
Swedish		0.425	0.40	160	1	0.12	1300	5.0	1:1	8– 15	8– 15	3.0	63
Weald (no.2)	50–300AD	0.30	0.66	300	1	0.40	1300	9.0	1:1	25– 80	10– 25	11.6	68
Ashwicken	R	0.30	1.00	300	1	0.41	1400	5.0	1:4	20– 50	– 3	3.5	53
Dimi	1974	0.4top 1.2base	1.00	3544	18	0.47	1420	4.0	3.28:1	20– 50	15– 25		

***This table has been taken from reference 9 and the Dimi material included for comparison.**

TABLE 4

Chemical Analyses of Ethiopian Furnace Slags and Clay

	S1 Gerfa	S2 Garo	S3 Garo	S4 Gerfa forge	Clay
Fe_2O_3	41.37	–	47.11	11.52	10.60
FeO	–	45.00		–	
SiO_2	28.73	34.50	32.19	63.19	67.20
MnO	2.01	1.25	nd	nd	0.07
Al_2O_3	21.94	14.30	16.67	11.16	14.10
CaO	5.73	1.40	nd	6.05	1.30
P_2O_5	ns	1.29	ns	ns	ns
TiO_2	ns	1.90	ns	ns	1.10
moisture loss	0.49	ns	0.47	0.46	ns
S	0.02	nd	<0.01	0.02	ns
Total	100.29	99.64	96.45	92.40	94.37

ns = not sought

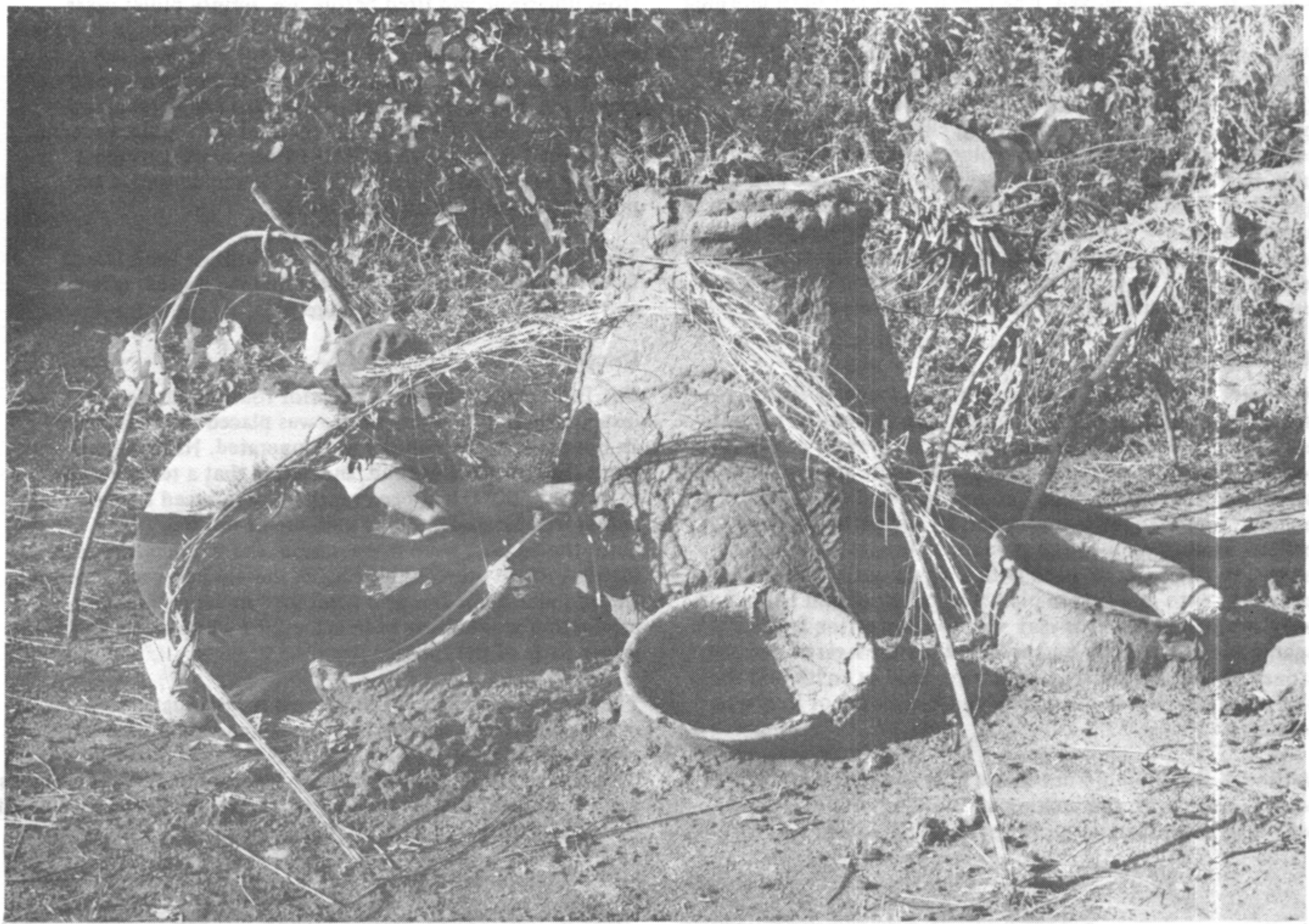


Fig 4 Furnace structure with six bellows around the base. (pipes not in position).

4.00pm The charcoal was now glowing red hot. Earth was brought in a wooden dish and made into clay, which was used to seal the large tuyeres into the base of the furnace. Small pipes were brought, cleared with a stick and sealed onto the bellows pots as described.

4.30pm The first scoop of ore was put in whilst the smith in charge continued fitting the pipes. Three wooden dishes of earth were used for clay.

5.00pm Cow dung was mixed with water and smeared around the inside of the bellows pots and rim and a little water was left in the bottom of the pots. It is not clear whether this was intended to prevent the pots from cracking or to provide moisture in the air draught. A green wood shelter was erected round the furnace to protect the operators from sparks. Either a goat or sheep skin was tied on each pot, the centre being weighted with a stone so that the skin was slack.

5.15pm Two scoops of charcoal were added followed by one of ore and two more of charcoal. The furnace was now full and the top gases were lit, indicating that the temperature in at least a part of the furnace must have reached 700°C, ie. that carbon monoxide was being produced.

5.40pm Another scoop of ore was added and six people, sitting on stones in front of each pot, began to operate the bellows. At this stage there were five men and one woman working, all members of the smith's family although other Dimi were welcome to take over. Eight people were available. The bellows were operated for a few bursts at the faster rate of sixty blows per minute and then at forty-seven blows per minute.

5.50pm Stopped for five minutes rest whilst the pipes were cleared.

6.10pm Another quick burst for forty-five seconds then slower speed adopted.

6.15pm Two scoops of charcoal were added, levelled with a stick, then one scoop of ore.

6.20pm Fast spurt for two minutes, then two more volumes of charcoal added and levelled, one more ore and one more charcoal. Everyone rested for a minute.

6.50pm One charcoal, one ore and another charcoal added.

6.55pm Stopped for dinner of sweet potatoes and water.

7.06pm Started again with a quick burst and worked steadily until . . . . . .

9.40pm Stopped completely. The smith could tell that the iron was ready from the noise made by the slag, the level of the furnace contents, which appeared to be at the tuyeres, and the colour of the flame. The goat skins were removed from the pots revealing that some water remained. Digging sticks were used to break the clay seals and both large and small pipes were removed. The furnace was left until morning

As soon as it was light at 6.30am the smith got up and loosened the furnace contents with a digging stick inserted through the top. Two gourds of water were poured in to quench the bloom. The smith's son climbed in through the top and started passing out the bloom which consisted of iron, slag and charcoal fritted together. There were also a few globular pieces of iron resembling cast iron, but the yield was agreed to be low. This was attributed to our attempts to take some flash photographs, the flash resembling lightning, which is always a bad omen during a smelt. The yield of iron was probably only sufficient to make two or three sickles.

The Forge

At a later date the iron was taken to the forge, (Figure 5) heated in a charcoal fire and forged with stones (or a blunt-ended iron hammer for smaller items) into larger pieces for tools. The forge was a roofed structure with open walls and consisted of a hearth, walled at one side and two drum bellows. The draught was supplied by a slightly different bellows arrangement to the reduction furnace; one man operating two bellows, each with a single outlet, which converged into one tuyere pipe. The operator and bellows were situated behind the clay wall for protection from sparks and at a slightly higher level than the hearth. Special stones obtained from river beds were used as anvils and for sharpening tools. No quenching and tempering of iron was observed.

Although the Dimi did not know how to smelt copper, they were familiar with the melting and forging of bullet cases, which was also carried out in the forge. A mould was carved from limestone and fired before use. Empty bullet cases were pounded flat after the primer had been removed, (this was used for decorating chairs), and they were placed in the mould, melted, cooled a little and the strip of metal quenched. Repeated heating, quenching and forging was carried out until the metal had reached the required length. It was then shaped for bracelets by hammering round a piece of wood, decorated with an iron pin or wedge and polished by rubbing on the ground.

The forge was also used for repairing broken tools (these were rarely thrown away) and sharpening knives, spears and farming implements. (Figure 6).

Discussion

The Dimi process involved no prior roasting of the ore, instead the first measure of ore was placed in the furnace an hour before the bellows were operated. Half an hour later, the top gases were lit, indicating that a temperature of at least 700°C had been reached by induced draught, and more charcoal and one measure of ore was added. Once the bellows were in operation, the temperature rose rapidly. As no previous heating of the ore had been involved, the elimination of free and combined moisture and any calcination would have been achieved by heating in the upper parts of the furnace itself.

The description of the Dimi process reveals that the overall fuel to ore ratio is 15:6 by volume and 1:3.3 by weight. (The density of the charcoal was found to be 0.3g/cc and the density of the ore was 2.46g/cc). Dr Tylecote's work[9] confirms that as the fuel to ore weight ratio is decreased from 2:1 to 1:4, the carbon dioxide content of the gas

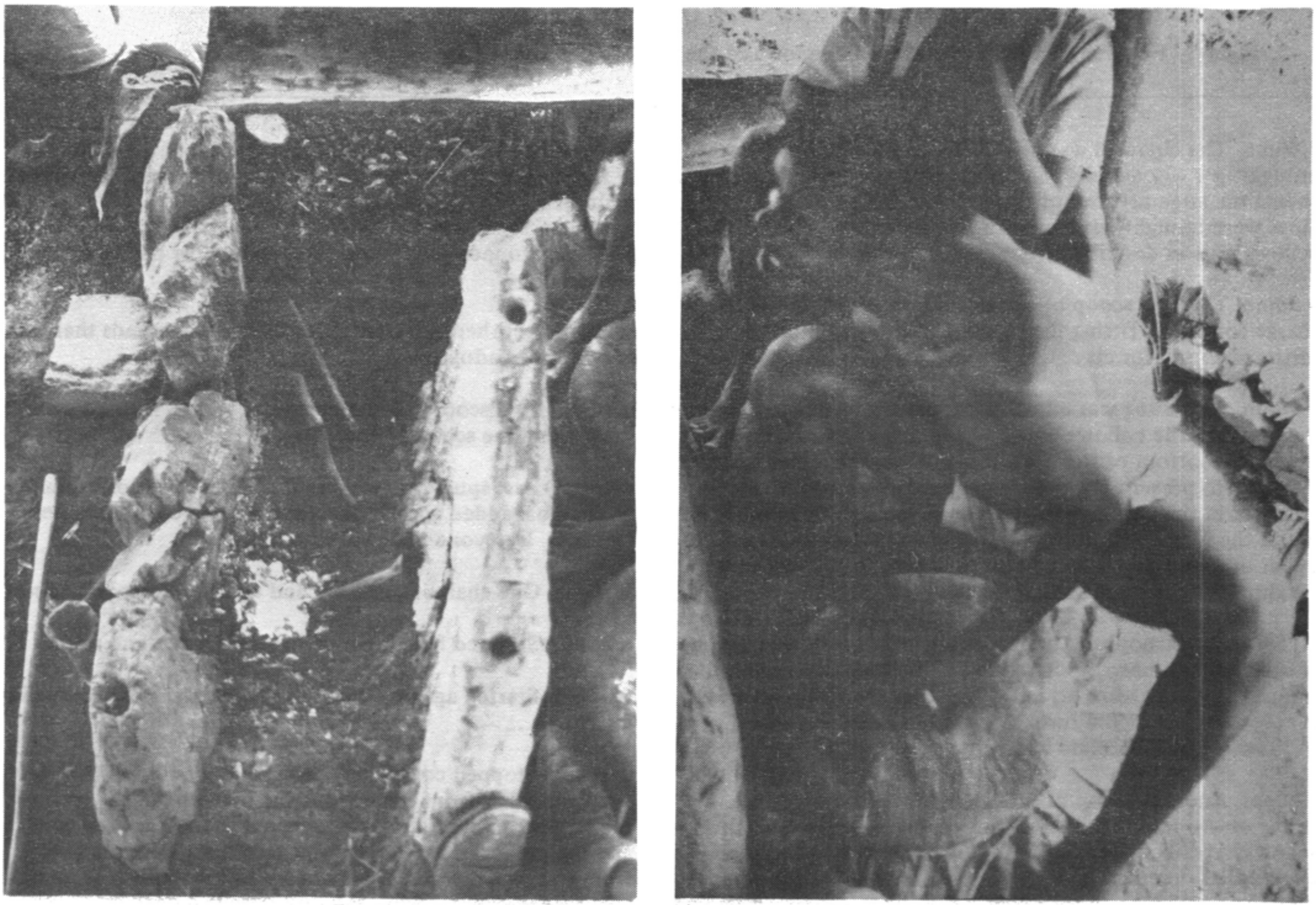


Fig 5 a) Forge hearth b) Forge bellows arrangement

TABLE 5

Analysis of Ethiopian Charcoal

Spectrographic

Considerable amounts –	**Al, Ca, Fe, Mg, Mn, Si**
Trace amounts –	**B, Cu, Pb**
Slight traces – –	**Mo, Ni, Ag**

Chemical analysis

K_2O – 0.10%, Na_2O – 0.01%, P_2O_5 – 0.026%, CaO – 3.7%,
Ti – very slight trace, Total ash at 800°C = 1.53%.

Ethiopian Bloomery Iron

Si – 0.17%, Mn <0.01%, C – 0.4%, S <0.01%, P – 1.01%

TABLE 6

Major constituents of slags (derived)

	S1	**S2**	**S3**	**S4**
FeO	42.35	47.97	46.45	12.24
SiO_2	32.69	36.78	35.28	74.59
Al_2O_3	24.96	15.25	18.27	13.17

TABLE 7

Standards for Quantitative Analysis

Standard	**Chemical composition**	**% element(s) analysed**
Wollastonite	$CaSiO_3$	Ca – 34.32 Si – 24.00
Orthoclase	$KAlSi_3O_8$	K – 12.40
Apatite	$Ca_5(PO_4)_3(F.Cl.OH)$	P – 18.42
Alumina	Al_2O_3	Al – 52.93
Periclase	MgO	Mg – 60.32
Jadeite	$NaAl(SiO_3)_2$	Na – 11.34
Metals	Fe, Mn, Ti, Cr, Ni, Cu, V, W	– 100%

Minerals are preferred in the case of elements such as silicon, aluminium, etc occurring as oxides in the inclusions (20).

increases, the carbon content of the bloom decreases and the percentage of iron in the slag increases. He found that ratio 2:1 gave the largest yield of iron, ie. cast iron, but the iron content of the slag was then too low to produce a free running slag. Slag which can be tapped is only produced with low fuel to ore ratios and consequently much iron is lost to the slag. Tylecote points out, however, that slag containing as little as 35% iron could be free running at 1150°C if it contained the right proportions of silica, alumina, magnesia and lime. The presence of gangue minerals, ie. a relatively impure ore is not, therefore, necessarily a bad thing in terms of furnace operation.

The furnace was non slag-tapping, thus eliminating any oxidation of the bloom and temperature drop in the furnace due to air admitted during such a process. The pit below ground level provided sufficient space for the bloom to consolidate and by the end of the reduction the furnace contents were below tuyere level. The slag enveloped the bloom and appeared to have sealed it into the hearth, preventing the bloom from re-oxidising when the tuyeres were removed. This was confirmed the following morning when a digging stick was required to break the bloom away from the furnace wall. The majority of the slag produced during the observed process could be distinguished from both a normally designated tap slag and cinder. Such tap slag shows a characteristic flow pattern as it solidifies on leaving the furnace, whereas cinder refers to the drossy unfused material which collects above the molten slag. Although a few pieces of slag revealed flow markings, the Dimi slag consisted mainly of fused, black droplets of slag containing vesicules, and a considerable proportion of entrapped charcoal. It is darker than Roman tap slags and has been referred to as 'schlackenklotz'.[10] The droplets have obviously been molten on passage through the tuyere zone, indicating that the slag could probably have been tapped, but since the non slag-tapping process produced satisfactory yields of iron at this scale, there was presumably no motivation to increase the complexity and difficulty of the process.

Addition of flux to the charge was not observed and the low wear of tuyeres and furnace wall appears to eliminate the clay from being a potential source of flux. The addition of flux could lower the viscosity of the silicate slag by decreasing the structural complexity (ie. breaking Si – 0 – Si linkages in the network structure), enabling the slag to separate from the metal more easily. The addition of lime to a silicate slag also increases the activity coefficient of wüstite in the oxide system and thus lower losses of iron to the slag would be expected.

The bloom was centrally situated in the furnace and was extracted through the top, limiting the damage to the furnace to cracking of the clay during the smelt. There was no lining to repair and the cracks were sealed with clay. Examination of the bloom showed a porous mass of iron resembling the consolidation of slag-coated iron particles. (Figure 7). The iron itself showed variable carbon content and appeared to have a low inclusion content. The yield of iron was low in the observed Dimi smelt, but it was reported that sufficient iron to make a pair of digging sticks could be produced by similar operation of the furnace.

During the course of the Dimi smelt samples of ore, charcoal, furnace slag, cinder,[11] furnace material and a discarded tuyere were collected. Unfortunately the smith would not part with the iron as the yield was considered low. However, samples of a bloom and iron ore were later obtained from a second site. A series of iron artefacts were also collected from the surrounding region for examination. (Figure 6).

Examination of the Ethiopian Bloomery Products

Analysis of Ores and Slags

Before undertaking chemical analysis, the ore and slag samples were analysed qualitatively, using a DC arc Hilger Large Littrow Spectrograph, and the elements present in major, minor and trace quantities were determined (Table 1).

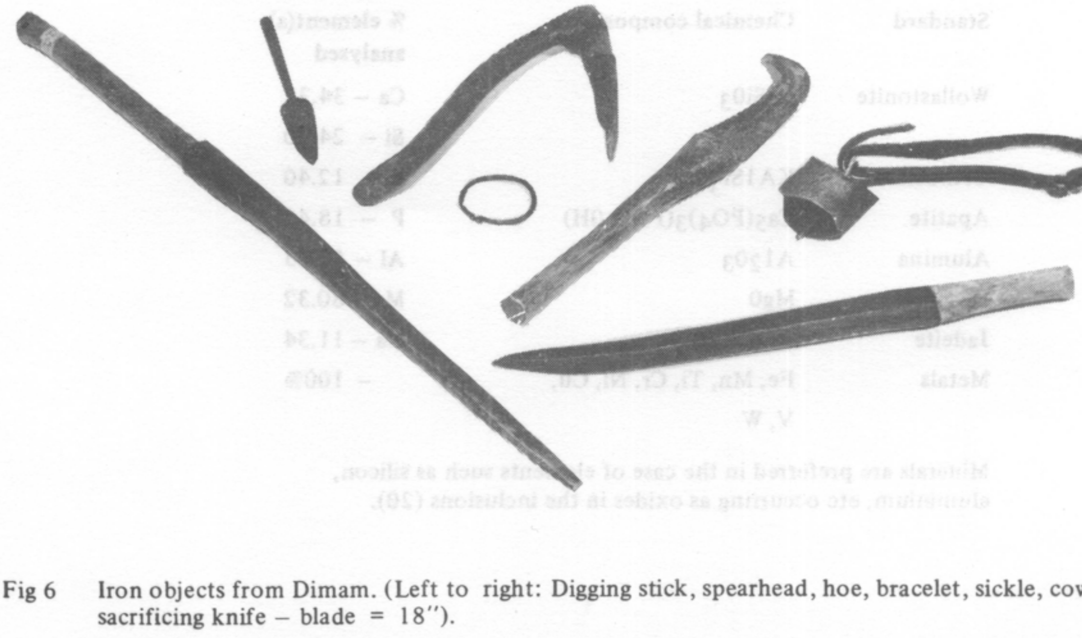


Fig 6 Iron objects from Dimam. (Left to right: Digging stick, spearhead, hoe, bracelet, sickle, cowbell, sacrificing knife – blade = 18").

TABLE 8

Raster analyses of Ethiopian Furnace Slag (S2)

(EDAX)

FeO	43.1	42.2	43.1	44.0
MnO	1.2	1.7	1.6	1.4
CaO	1.2	1.2	1.1	1.1
SiO_2	35.8	34.3	34.8	35.1
K_2O	1.4	1.5	1.4	1.3
Al_2O_3	13.0	12.7	13.6	12.7
TiO_2	2.2	2.1	2.0	2.3
P_2O_5	–	–	1.0	1.0
	97.9	5.7	98.6	98.9
$\frac{CaO}{SiO_2}$	0.034	0.035	0.032	0.031

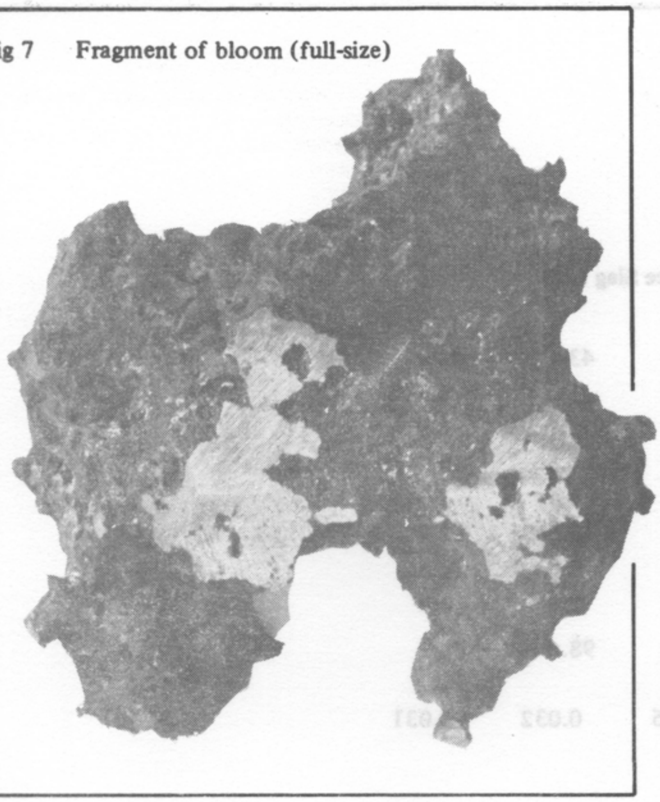
TABLE 9

Spot analyses of heated and quenched Ethiopian slag (S2)

(EDAX)

FeO	42.5	41.8
MnO	1.2	1.5
CaO	1.4	1.4
SiO_2	37.3	35.9
K_2O	1.5	1.4
Al_2O_3	13.1	12.4
TiO_2	2.0	2.0
P_2O_5	1.0	1.1
MgO	1.4	1.0
	101.4	98.5
$\frac{CaO}{SiO_2}$	0.038	0.039

Fig 7 Fragment of bloom (full-size)



It should be emphasised that the terms 'trace', elements etc in this analysis refer to the directly observed intensity of the spectral lines rather than to the probable concentration of elements in the sample (which would involve repeated comparison with standard plates). Owing to the variability of conditions in the arc, differences observed in the line intensities may or may not indicate actual differences in the composition of the sample. Sulphur is not detected by conventional spectrography since the wavelength lies in the far ultra violet range and the detection of phosphorus is only moderate. Once the elements present in the ore and slag had been determined, the major and minor elements (ie >0.1wt%) were determined by standard wet chemical analysis methods (Table 2).

Analyses S1, S2 and S3 in Table 4 represent slags collected from the observed site and a different site, and S4 is an example of slag removed from the end of a forge pipe. The high silica content of the latter may be due to reaction of the slag with the pipe. (See clay analysis in Table 4). An estimate of the minimum temperature reached in the furnace can be made from chemical analysis of the slag by plotting the major constituents on a ternary phase diagram and assuming that the whole slag has been molten. It is possible, of course, to produce a pasty slag condition in which a high melting point component from the system has never fully passed into solution. It is generally accepted that any ferric ion found in the slag is due to oxidation in the tuyere zone, the material not passing into the reducing zone; or that oxidation has taken place outside the furnace, eg on tapping, or forging of the bloom. If the ferric oxide content of the slags is converted to wüstite ($Fe0$) and the slag constituents converted to percentages, the compositions given in Table 6 are obtained. When S3 is plotted on the $Fe0 - Si0_2 - A1_20_3$ phase diagram, the liquidus temperature is found to be 1400°C (Figure 8).

Microscopical examination of the slag (Figure 9) shows constituent phases to be an iron alumino-silicate and fayalite ($2Fe0.Si0_2$), Figure 10. Conversion of the lime in S1 to anorthite leaves excess alumina, which makes it impossible to follow the method of Morton and Wingrove[12,13] in plotting the slag composition on the anorthite – $Fe0 - Si0_2$ phase diagram, since the percentage of excess alumina is too high to be ignored. An approximate temperature estimate can be obtained by assuming that the lime ($Ca0$), manganous oxide ($Mn0$) and wustite contents are equivalent on a molar basis (although Bodsworth[14] points out that these oxides are not exactly equivalent). This would give the composition $Fe0$ – 35.57%, $Si0_2$ – 36.53%, $A1_20_3$ – 27.90%, which gives a liquidus temperature of 1420°C. A similar treatment of S2 gives a liquidus temperature of 1200°C.agreeing with experimental results which showed that the individual slag drops separately heated were free-running at 1150°C. Therefore, the bulk chemical analyses of slags S1 and S3 indicate that the analysed material was fused with cinder, emphasising the care that must be taken in distinguishing samples of furnace slag and cinder.

Analysis of materials using the scanning electron microscope with energy dispersive X-ray analysis

Understandably many reports concerning bloomery products contain relatively few analyses. Detailed chemical analysis of an ore or slag may take several days, and a single spot analysis for fourteen elements using the microprobe may take several hours. An analysis survey of many different inclusions, which may be multi-phased, can, thus, also take considerable time. It was therefore decided to carry out comparative analyses using energy dispersive X-ray methods (Stereoscan with EDAX), as the time required to make a single measurement of all elements in a given region, whose atomic numbers lie above that of sodium, is then of the order of minutes. A brief description of the technique follows.

Electrons are accelerated through a potential, eg 20kV, to provide a high energy electron beam which can be focussed to a minimum of 500Å diameter. This beam excites a small volume of material and X-rays characteristic of the elements present in that volume are emitted. As these X-rays enter a silicon solid state detector, the pulses resulting at the different energy levels are amplified, and digitizing, storage and display of the energy spectrum is carried out by a multichannel pulse height analyser.

The output is displayed on a screen for rapid identification of the elements present, but since no computer attachment was available for immediate processing of the data, the information was also printed onto paper tape. The spectra recorded in this manner were transferred to magnetic tape and displayed on a Vector Graphics Display Unit (PDP 11/45). All the peaks in the spectrum then had to be corrected by subtracting the background counts and a computer program was written for this purpose.[15] The correction procedure involves superimposing a peak of the same full width at half maximum as the displayed peak, on the correct part of the spectrum, and the size and position of this peak was adjusted manually until the background fitted smoothly under the peak. Examples of an original spectrum and a corrected display are given in Figures 11 and 12. The calculated peak, which can be corrected to an accuracy of 0.2% can be clearly observed and represents the original peak minus the background correction. The integrals of the corrected peaks were compared with those from standard materials (Table 7) to obtain an apparent concentration, which is then further corrected for absorption, fluorescence and atomic number effects, according to the computer program of Duncumb and Jones[16]. Energy dispersive techniques are now well documented in the literature and the reader is referred to references 17–19 for further details.

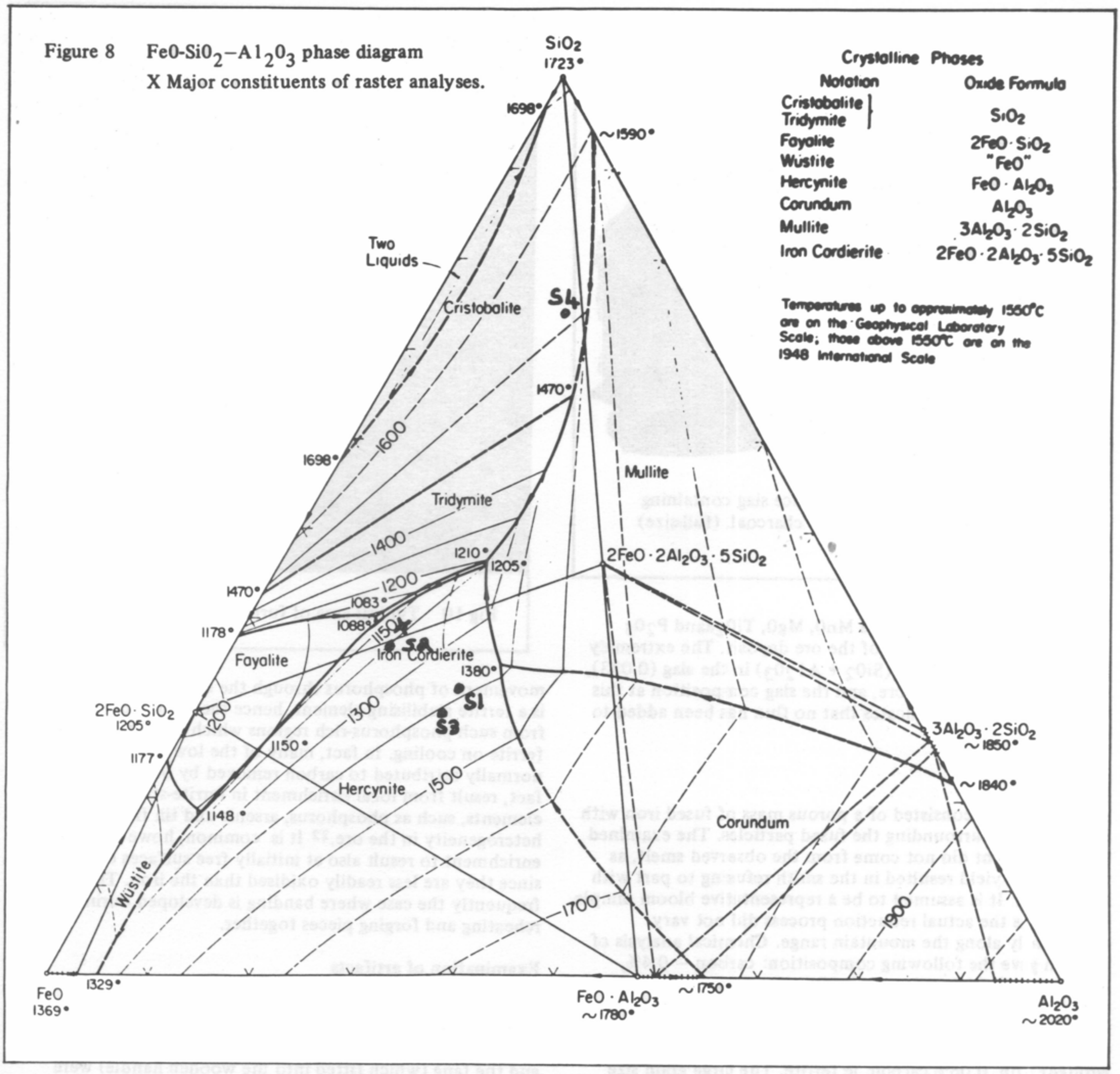


Figure 8 $FeO-SiO_2-Al_2O_3$ phase diagram

X Major constituents of raster analyses.

Although this correction procedure was lengthy, it was unavoidable as direct computing facilities were not available. More modern instruments will compare spectra of standard materials and elements present in a sample directly and produce an apparent concentration.

The Stereoscan and Edax were used to examine the furnace slag and the inclusions trapped in the finished artifacts. It was found possible to obtain analyses which represented the bulk composition of the slag ie raster analyses, made by scanning the electron beam over areas of the sample containing representative slag phases. Such analyses are given in Table 8 for comparison with S2 in Table 5. Spot analyses on the individual slag phases were also made and these are shown in Table 10. When the wüstite, silica and alumina components of the raster analyses are approximated to 100% and plotted on the $FeO-SiO_2-Al_2O_3$ phase diagram the results are found to cluster in the temperature range 1150°C – 1200°C, agreeing with the value for S2.

The raster analyses are consistent with those quoted by Tylecote[21] and Morton and Wingrove[13] for mediaeval slags. It is certainly true that the EDAX analysis only scans a very small area by comparison with chemical analysis of a sample weighing five or ten grams. With care in selection of raster area, EDAX analysis was found to agree with both chemical and microprobe analysis and it does enable individual phases to be identified easily. The individual phase analyses show that MnO and MgO replace FeO in the fayalite, whereas CaO, K_2O, TiO_2 and P_2O_5 preferentially concentrate in the anorthite. Raster analyses of the slag indicate a calcium content of 1.23%, which probably represents the concentration of calcium in the ore, in view of the calcium content of 06. However, it should be noted that the concentration of the calcium in the anorthite phase has been found to be as high as 4%. The calcium content of the charcoal was low, 0.17%, but significant transfer of calcium from charcoal to slag was expected. Similarly, reaction with the furnace clay appeared to be minimal.

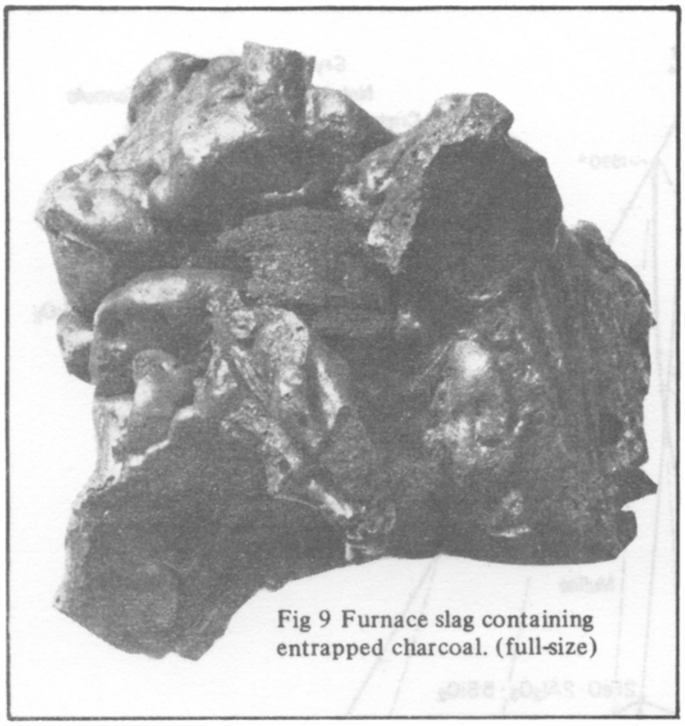


Fig 9 Furnace slag containing entrapped charcoal. (full-size)

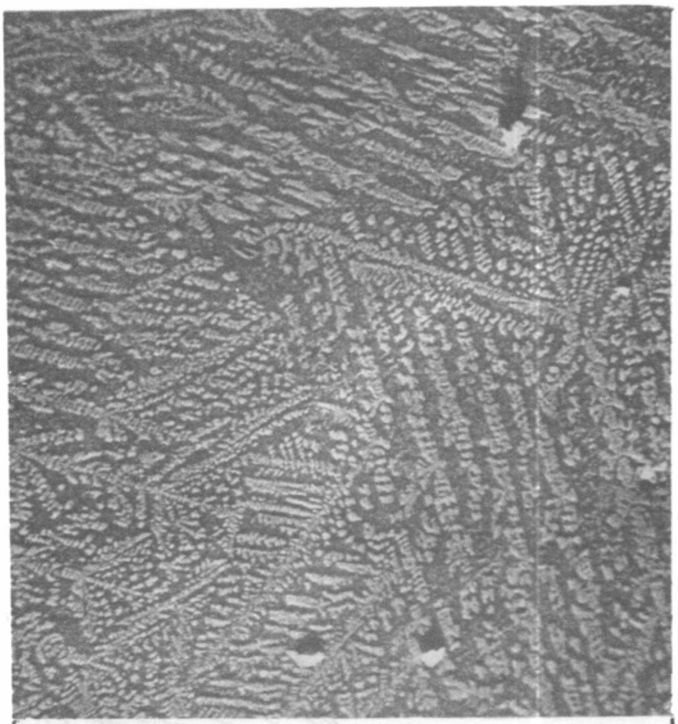


Fig 10 Typical area of furnace slag. Mag. X530.

It can be seen that the oxides MnO, MgO, TiO_2 and P_2O_5 are certainly characteristic of the ore deposit. The extremely low ratio of $(CaO + MgO)/(SiO_2 + Al_2O_3)$ in the slag (0.033), reflects this ratio in the ore, and the slag composition at this stage of the process indicates that no flux has been added to the ore.

The Iron

The iron bloom consisted of a porous mass of fused iron with a layer of slag surrounding the fused particles. The examined bloom fragment did not come from the observed smelt, as the low iron yield resulted in the smith refusing to part with his product. It is assumed to be a representative bloom sample, however, as the actual reduction process did not vary significantly along the mountain range. Chemical analysis of the iron gave the following composition: carbon – 0.4%, manganese <0.01%, silicon – 0.17%, phosphorus – 1.01%, sulphur <0.01%. Metallographic examination of a polished surface, etched in a 3% nital solution, revealed a variable carbon composition, from a eutectoid steel, 0.8% carbon, to wrought iron, 0.06% carbon, ie ferrite. The large grain size and coarse lamellar spacing of the pearlite confirmed the slow rate of cooling. In general, low carbon areas were located around the edges of the fragments, indicating that the iron either decarburised on passing through the tuyere zone, or on cooling in an oxidising atmosphere. However, conditions must have been reducing in most areas of the hearth as there are many other fragments of uniformly high carbon content.

It is important to note that the Dimi did not apparently attach any importance to the extent of carburisation of the bloom, which was extracted from the furnace as a steel and subsequently largely decarburised during working. Tylecote[9] records that the earliest iron formed in his experiments was entirely ferritic and attributes the higher carbon content of the bloom centre and top section to conditions becoming more reducing as the smelting proceeded. Etching with Oberhoffer's reagent (Table 11) revealed a variable phosphorus content, which would be expected from the inhomogeneous distribution in the ore and the fact that the diffusion coefficient of phosphorus in iron at 1300°C is relatively slow as compared to that for carbon, with therefore, very limited movement of phosphorus through the structure. Phosphorus is a ferrite stabilising element, hence the carbon diffuses away from such phosphorus-rich regions which transform first to ferrite on cooling. In fact, many of the low carbon regions normally attributed to carbon removed by oxidation may, in fact, result from local enrichment in ferrite-stabilising elements, such as phosphorus, arsenic and tin from original heterogeneity in the ore.[22] It is common, however, for such enrichment to result also at initially free surfaces on oxidation, since they are less readily oxidised than the iron. This is frequently the case where banding is developed during reheating and forging pieces together.

Examination of artifacts

(a) Knife

The knife was a much smaller version of that shown in Figure 6 and horizontal and longitudinal sections of both the blade and the tang (which fitted into the wooden handle) were studied. The centre part of the blade was ridged in articles such as knives, spears and sickles indicating that the iron was worked from the centre to the blade edges. Before purchase, the knife had been in general use and the blade edges contained some defects attributable to corrosion around entrained slag particles.

The horizontal section (ie the section perpendicular to the length of the blade) was again variable in carbon content between limits of approximately 0.02 to 0.2% carbon; considerably lower than the average carbon content of the bloom. The presence of a long weld defect containing slag particles indicates that the thickness was formed by hot forging two pieces of iron together, and the direction of elongation of many slag inclusions confirms that a principal direction of forging was from centre to edge. The outer surface of the section was decarburised, apart from one small area where a maintained carbon content extended to the edge. This reflects the generally oxidising conditions of forging, as the artifacts were placed in the charcoal fire, close to the tuyere, heated to an orange colour, removed and forged until the colour died away.

TABLE 10

Analyses of individual phases of the Ethiopian furnace slag (S2) (EDAX)

Light phase				
Fe0	66.0	66.4	63.9	67.7
Mn0	2.2	2.4	1.8	2.5
Ca0	–	–	0.3	–
$Si0_2$	27.7	27.1	29.1	27.1
K_20	–	–	0.3	–
Al_20_3	–	–	3.6	–
$Ti0_2$	0.3	–	0.9	–
P_20_5	0.8	1.1	1.0	0.9
Mg0	1.4	1.3	–	1.8
	98.4	98.3	100.9	100.0
$\frac{Ca0}{Si0_2}$			0.010	
Dark phase				
Fe0	27.3	21.6	36.1	21.2
Mn0	1.1	1.2	0.9	1.2
Ca0	2.7	4.2	1.0	3.9
$Si0_2$	41.9	47.9	38.6	50.0
K_20	2.1	2.3	1.7	2.5
Al_20_3	15.7	15.2	18.7	16.0
$Ti0_2$	6.7	1.6	2.9	1.7
P_20_5	2.1	3.7	1.7	3.1
Mg0	–	1.0	–	–
	99.6	98.7	101.6	99.6
$\frac{Ca0}{Si0_2}$	0.064	0.088	0.026	0.078

TABLE 11

Oberhoffer's reagent (Modified ferric chloride)

$FeC1_3$	30.0 ml
$CuC1_2$	1.0 ml
$SnC1_2$	0.5 ml
HC1	50.0 ml
Ethyl Alcohol	500.0 ml
H_20	500.0 ml

TABLE 12

Single phase inclusions in Ethiopian Knife – Weight %

	microprobe				EDAX
FeO	55.6	55.3	55.5	54.7	54.3
MnO	1.1	1.2	1.3	1.3	1.4
CaO	4.5	3.2	4.2	3.1	2.6
SiO_2	24.0	22.0	26.5	23.3	23.8
K_2O	1.4	1.1	1.5	1.9	1.3
Al_2O_3	6.4	6.8	7.5	6.9	7.0
TiO_2	0.5	0.8	0.5	0.9	0.8
P_2O_5	5.5	11.9	7.7	5.6	11.3
MgO	–	–	–		1.2
	99.0	102.3	103.7	97.7	103.7
$\frac{CaO}{SiO_2}$	0.188	0.145	0.158	0.133	0.109
FeO	53.3	53.4	61.8	50.6	48.6
MnO	1.2	1.3	1.3	1.3	2.2
CaO	2.6	4.0	2.9	3.3	3.5
SiO_2	21.7	26.6.	22.0	27.0	18.4
K_2O	2.5	2.3	1.0	1.7	0.3
Al_2O_3	5.1	8.3	5.0	7.8	5.8
TiO_2	12.8	4.4	4.2	11.3	22.1
MgO	–	–	–	–	2.2
	100.0	100.9	99.3	104.0	103.8
$\frac{CaO}{SiO_2}$	0.120	0.150	0.132	0.122	0.190

TABLE 13

Two phase inclusions in Ethiopian knife (EDAX) – Weight %

	Light Phase 1	**Light Phase 2**	**Light Phase 3**	**Light Phase 4**
Fe0	94.5	98.3	96.7	90.0
Mn0	–	–	–	0.1
Ca0	0.2	–	–	0.3
$Si0_2$	0.6	0.6	0.6	3.6
K_20	–	–	–	0.4
Al_20_3	1.4	–	0.8	3.4
$Ti0_2$	2.4	0.7	1.1	0.6
P_20_5	0.3	–	–	1.0
Mg0	–	–	–	0.6
	99.4	99.6	99.2	100.0
$\frac{Ca0}{Si0_2}$	0.333			0.083

	Dark Phase 1	**Dark Phase 2**	**Dark Phase 3**	**Dark Phase 4**
Fe0	49.9	55.9	50.8	60.7
Mn0	0.4	0.3	0.5	0.3
Ca0	3.9	2.6	4.0	2.9
$Si0_2$	28.7	20.9	27.4	23.0
K_20	1.6	2.3	2.1	1.5
Al_20_3	10.0	6.2	9.0	6.9
$Ti0_2$	0.3	–	–	0.3
P_20_5	5.8	10.4	6.2	4.0
Mg0	1.7	1.6	1.6	1.1
	102.3	100.2	101.6	100.7
$\frac{Ca0}{Si0_2}$	0.136	0.124	0.146	0.126

TABLE 14

Slag phases in Quenched Ethiopian Knife Section (EDAX) – Weight %

FeO	56.2	53.3	55.6	55.7	53.5
MnO	1.2	1.4	1.5	1.3	1.4
CaO	2.6	2.9	3.4	3.1	3.5
SiO_2	13.4	21.7	22.8	22.9	24.7
K_2O	0.9	1.0	0.5	0.1	6.8
Al_2O_3	4.6	6.0	6.1	6.0	0.8
TiO_2	0.7	0.9	0.9	0.9	4.2
P_2O_5	12.1	9.8	5.9	5.8	1.2
MgO	–	–	1.1	1.2	–
	96.7	97.0	97.8	97.0	96.1
$\frac{CaO}{SiO_2}$	0.141	0.134	0.149	0.135	0.142
FeO	53.2	54.6	44.4	40.6	54.4
MnO	1.7	1.0	2.0	1.7	1.4
CaO	3.6	2.6	5.5	4.5	2.6
SiO_2	25.5	19.5	29.0	35.5	23.9
K_2O	0.2	1.1	0.4	1.0	0.5
Al_2O_3	7.0	5.2	7.7	9.4	5.2
TiO_2	0.9	0.8	1.0	1.1	1.0
P_2O_5	4.0	12.1	5.1	2.6	7.2
MgO	1.4	1.4	1.8	1.3	0.7
SO_3	0.6	–	–	–	–
	98.1	98.3	96.9	97.7	96.9
$\frac{CaO}{SiO_2}$	0.141	0.133	0.190	0.127	0.109

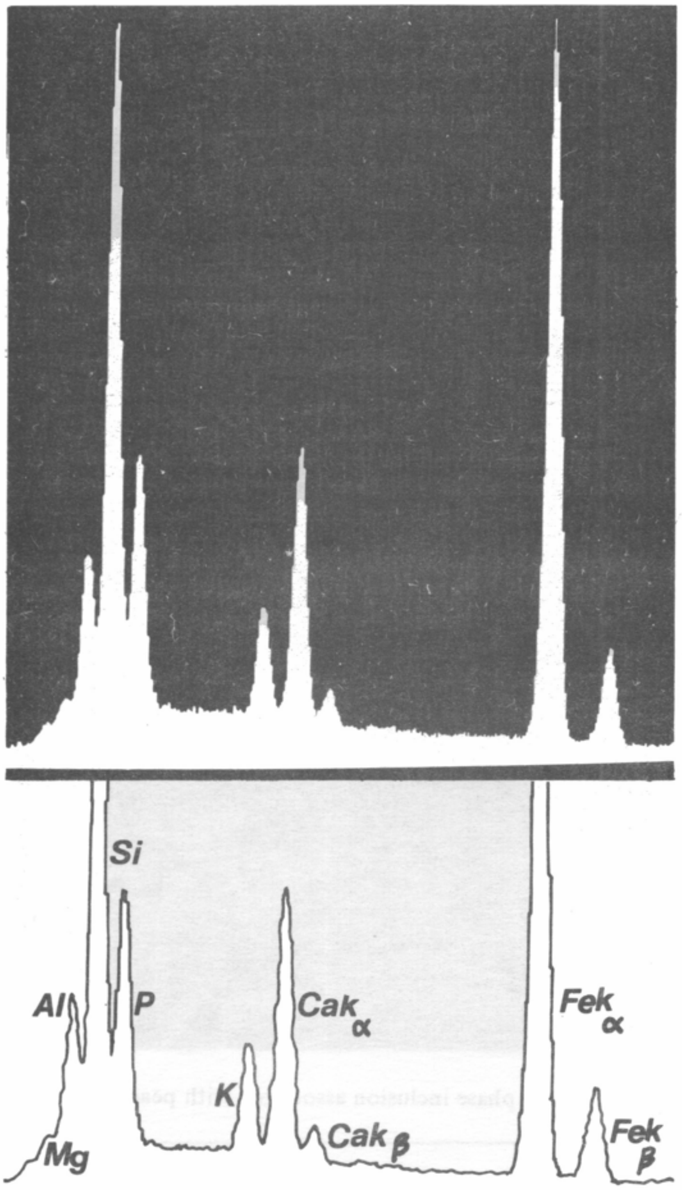


Fig 11

EDAX spectrum showing Mg, Al, Si, P, K, Ca, Fe peaks.

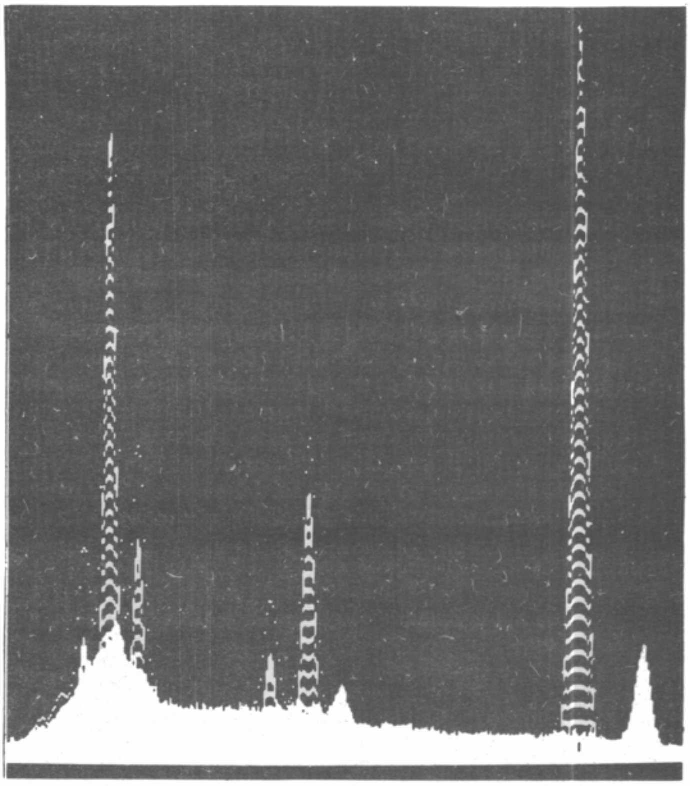


Fig 12

Corrected EDAX spectrum (CaK β & FeK β uncorrected).

The carbon content had a banded appearance across the section, which was initially thought to be fortuitous rather than deliberately produced. The central region was ferritic with a large grain size and was surrounded by a series of alternate bands of higher carbon content and ferrite (Figure 13). Many of the inclusions lay along grain boundaries and were associated with a little pearlite, which was surrounded by a ferritic region. Etching with Oberhoffer's reagent revealed that phosphorus was distributed in the large, ferrite grains, was not segregated to the grain boundaries and more importantly, that areas immediately adjacent to the inclusions were associated with pearlite and appeared to be lower in phosphorus than the rest of the grain. This depleted zone was too small to be detected by the microprobe electron beam, but was observed when using a very fine beam on the stereoscan.

It would appear that on forging, after initial higher temperature production, phosphorus has been oxidised from a zone of iron surrounding the inclusion into the slag phase, the ozygen being supplied by the FeO in the inclusion. (P_2O_5 becomes more stable than FeO with decreasing temperature). These results are consistent with those of Dr Tylecote,[21] who states that 'phosphorus is slightly more base than iron and does not accumulate at the metal-oxide interface during oxidation, but enters the oxide film as a phosphate'. The phosphorus depleted zone, therefore, accounts for the association of pearlite with these inclusions since carbon from the surrounding iron transforming first from austenite to ferrite would diffuse to the areas of lower phosphorus concentration, along the most rapid diffusion path, ie the grain boundaries (Figure 14).

The phosphorus entering the silicate slag inclusion would tend to break down the network structure, producing a more fluid slag, which accounts for the thin elongated morphology of the high phosphorus inclusions. As the width of the inclusions decreases, the phosphorus content appears to increase, and this may be a consequence of the greater metal surface area in contact with the inclusion per unit volume of inclusion material. The phosphorus composition of an ore is therefore reflected in the phosphorus content of the iron and the furnace slag, but it may not be possible to correlate the phosphorus content of inclusions directly with the level of phosphorus in the ore, in view of subsequent interaction during working and cooling.

The lamellar pearlite had begun to spheroidise in some regions, reflecting the variable reheating temperatures and cooling rates of the different parts of the blade. The large ferrite grain size could have arisen either by (a) transformation to austenite and grain growth, suggesting that a temperature of greater than 900°C must have been reached in the forge, or (b) a ferrite recrystallisation anneal at approximately 600°C following a degree of cold work. Microhardness measurements range from 220 VPN in the more highly carburised regions to 137 VPN in the ferrite areas. Since there is no evidence of remaining cold work, the latter value reflects the phosphorus content of the iron, As Gove[23] has measured a microhardness of 85 VPN for pure iron at 20°C.

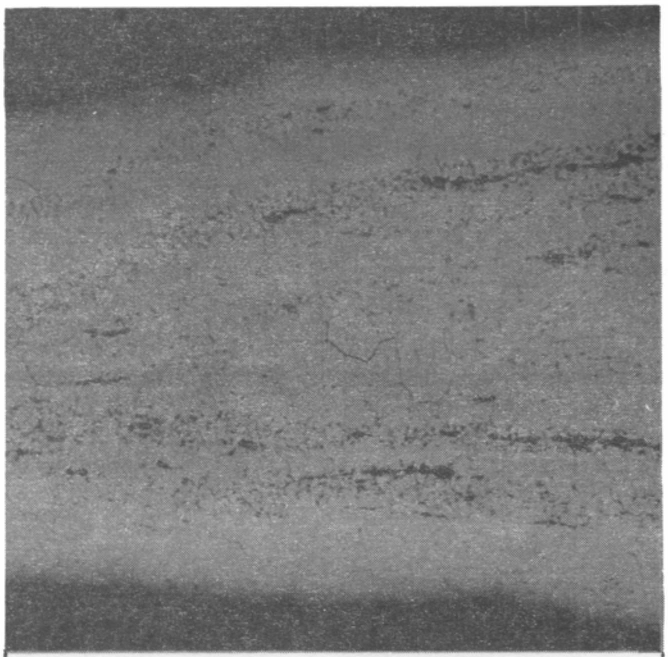


Fig 13 Etched microstructure of Dimi knife X28.

Both single and two phase inclusions were observed with a variety of morphologies.

(a) single phase inclusions, many of which had elongated and subsequently cracked as deformation continued below the glass transition temperature.

(b) rounded globules or fine dendrites of a light phase (FeO) in an apparently single phase matrix. However, stereoscan photographs reveal that the matrix has a dendritic microstructure resembling that of the slag, (Figure 15). Analyses of the single and two phase inclusions are given in Tables 12 and 13.

The iron content of the single phase inclusions is higher than that of the raster analyses of the furnace slag and is consistent with a fluid slag phase taking more iron into solution, in an oxidising atmosphere. In the two phase inclusions, the excess iron has then separated as wüstite on slow cooling. The most significant composition difference between the furnace slag and the single phase inclusions is the high phosphorus content of the latter, which has been discussed above.

One very important point immediately arises from this discussion. Examination of the inclusion analyses establishes that the P_2O_5 content of the inclusions did not arise as the result of flux deliberately added to remove phosphorus from the metal, but is a direct consequence of the high phosphorus content of the iron and the increased stability of ferric phosphate with decreasing temperature. Hence, the presence of high phosphorus inclusions in such artifacts is not associated with the use of flux or a higher level of technological skill. Similarly the classification of iron artifacts by their phosphorus content should also be approached with caution. A wide range of final values in the product from a given raw material could be obtained by variations in local furnace conditions and the degree of slag phase separation.

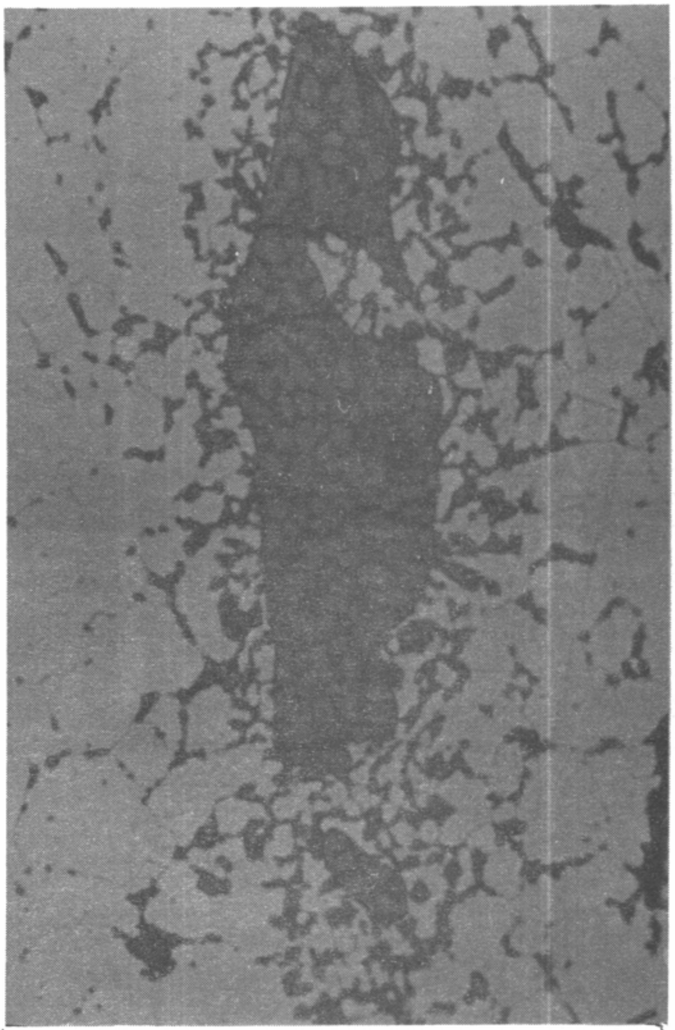


Fig 14 Two phase inclusion associated with pearlite X750

The manganous oxide content of the furnace slag appears to be preferentially associated with the fayalite, whereas calcium and potassium form more stable silicates and are associated with the phase containing higher silica. The inclusions in the knife show constant values of manganous oxide in the range 1 to 2%, although in view of the value of up to 4% observed in the ores, the figure of 1% to 2% might seem low. This will be discussed in a later section. The percentages of potassium oxide and lime in the single phase, and the dark phase of the two phase inclusions, are the same order of magnitude as in the furnace slags. Very strongly reducing conditions are required for manganese to appear in the iron and, although this is achieved by solid state reduction of magnetite ores in the Swedish Hoganas process employing sealed 'saggers', Tylecote[21] points out that manganese present in ores which are smelted by the primitive bloomery method rarely appears

TABLE 15

Single and Two phase inclusions in Ethiopian Digging Stick – Weight %

	Dark Phase Elongated Inclusion	Raster Two Phase Inclusion	Light Phase	Elongated Inclusion
Fe0	57.1	58.4	92.92	44.3
Mn0	1.7	1.7	0.6	0.5
Ca0	2.1	2.1	–	–
$Si0_2$	28.3	27.6	1.9	–
K_20	1.0	1.2	–	–
Al_20_3	5.8	6.7	–	54.7
$Ti0_2$	0.8	0.9	1.2	0.6
P_20_5	4.3	5.1	0.3	–
Cu0	1.1	1.0	1.0	0.4
	102.2	104.7	97.9	100.5
$\frac{Ca0}{Si0_2}$	0.074	0.076		

	Single Phase	Single Phase	Single Phase
Fe0	2.7	2.6	2.8
Mn0	1.6	1.8	1.4
Ca0	5.7	5.4	5.1
$Si0_2$	55.4	56.5	56.3
K_20	3.5	3.4	3.1
Al_20_3	27.4	26.8	27.7
$Ti0_2$	3.0	3.9	3.1
Mg0	–	3.9	3.8
Cu0	0.5	0.6	0.7
	99.8	104.9	104.0
$\frac{Ca0}{Si0_2}$	0.103	0.096	0.091

TABLE 16

Analyses of slag phases and iron from 06 (Ethiopian reduced at 1200°C) (EDAX) – Weight %

	Slag phases			
$Fe0$	6.7	0.9	4.7	8.4
$Mn0$	12.1	0.4	12.3	5.0
$Ca0$	1.1	–	1.1	–
$Si0_2$	46.9	23.8	45.8	–
K_20	0.5	–	0.6	–
Al_20_3	19.9	71.0	19.	81.6
$Ti0_2$	8.1	3.0	8.5	2.9
Cr_20_3	–	–	0.2	–
$Mg0$	1.8	–	–	–
V_20_5	2.6	–	2.9	–
	99.7	99.1	95.1	97.9
$\frac{Ca0}{Si0_2}$	0.023		0.024	

	microprobe				**EDAX**
	Slag	**Iron**		**Iron**	
$Fe0$	1.688	Fe	97.208	98.423	100.1
$Mn0$	19.932	Mn	0.193	0.049	–
$Ca0$	1.736	Ca	0.034	0.046	–
$Si0_2$	40.325	Si	0.025	0.027	0.2 *
K_20	0.476	K	0.010	–	–
Al_20_3	22.259	Al	–	–	–
$Ti0_2$	6.468	Ti	0.016	–	–
P_20_5	0.027	P	0.741	0.442	0.6
$Mg0$	2.102	Mg	0.010	0.047	–
$Ni0$	0.067	Cr	0.008	0.002	–
		Cu	0.033	0.005	–
		V	0.015	–	–
		S	–	0.047	–
	95.076		98.288	99.151	100.9
$\frac{Ca0}{Si0_2}$	0.043				

* Silicon excited in the solid state detector

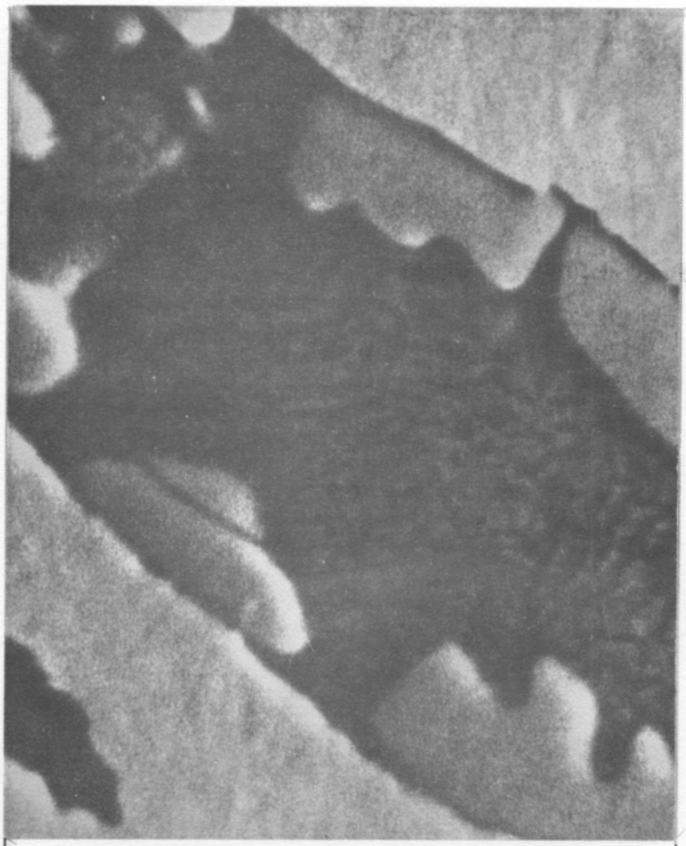


Fig 15 Two phase inclusion showing fine dendrites in matrix X6,300.

in the iron. This is supported by the low values of manganese found in Dimi iron.

It was sometimes found difficult to estimate the 'bulk' composition of the inclusions containing a second phase where the matrix and second phase were strongly separated, and to facilitate comparison with the slag raster analyses, a section of the knife was heated for a short period at 1200^{o}C in an argon atmosphere and quenched, preventing crystallisation of the inclusion and retaining a glassy single phase state. Analyses of these inclusions are given in Table 14. It can be seen that the lime/silica ratio in the inclusions is generally higher than for the area analyses of the furnace slag. This may suggest that on forging the bloom, the fayalite phase (melting point 1150^{o}C) was more fluid than the matrix and was preferentially squeezed out of the bloom, particularly in view of the small number of fayalite inclusions.

(b) Digging Stick

The longitudinal section again revealed a decarburised outer zone with a larger grain size than the central region, where the carbon content reached 0.7% in places. Again, higher carbon regions occurred in bands which sometimes extended to the outer surface. Large elongated inclusions were observed in the low carbon region, although very thin stringers were not found, and the inclusions of the central region were smaller and less deformed. Forging of the point would be carried out with periodic rotation of the digging stick resulting in more uniform deformation of the bulk and maximum deformation in the surface layers.

The inclusions were of similar appearance to those in the knife, some having a marked dendritic structure resembling the furnace slag. Typical inclusion analyses are given in Table 15 and it can be seen that single phase inclusions of similar composition to those in the knife are present. Angular hercynite ($Fe0.Al_2 0_3$) was also found in some of the larger inclusions.

The single phase inclusions found in the central high carbon region were alumino-silicates with a much lower Fe0 content and higher lime than the other inclusions, although the lime/silica ratio was, in fact, the same order of magnitude as in the knife inclusions.

Deformation of inclusions

An important aspect of previous work on non-metallic inclusions in steel has been detailed studies of inclusion deformation with respect to their intrinsic mechanical properties, as dictated by chemical composition. The relative plasticity of inclusion and metal have been defined by a deformability index, ie the ratio of true strain in the inclusion to true strain of the steel, which enables the degree of deformation of the metal in a given temperature range to be determined. In the present work, only qualitative observations can be made from the degree of extension of the inclusions. The direction of working can be established and if the inclusions compositions are of known characteristics an indication of the temperature of working can be obtained. Complicating features such as the incorporation of many separate pieces of iron and the re-use of previously forged materials, limit the use of the deformability index concept in the case of primitive iron artifacts.

Reduction of iron ores

The Ethiopian furnace slag and inclusion compositions both included relatively low percentages of manganous oxide as related to the concentration in ores 03 and 04. To investigate this relationship further, samples of 03 and 06 were reduced in an atmosphere of carbon monoxide at temperatures of 1200^{o}C and 1300^{o}C. The compositions of iron and slags produced are given in Tables 16 to 18. It can be seen that the slag phases produced by 06 at both temperatures contained up to 20% Mn0, whereas the slag from reduced 03 contained less than 1%Mn0.

Comparison of the experimental slag analyses with those of the Ethiopian furnace slag (S2) reveals a close similarity between the slag from reduced 03 (Table 18), and the raster analyses of the furnace slag (Table 8). The manganese content of the experimental iron is the same as that of the bloom. The experimental slag was quenched in order to obtain a single phase glass, but on slow cooling, equilibrium phases would separate and it is probable that Mn0 would associate preferentially with a particular phase, as in the two phase furnace slag.

It is clear from the diffrent Mn0 contents of the experimental slag products that the knife and digging stick examined have been made from an ore similar in composition to 03 rather than to 06. Comparison of the inclusion compositions with the experimentally reduced 03 suggests that temperatures of 1300^{o}C were reached in the Ethiopian bloomery process. The high Mn0 slag phases of reduced 06 confirms that the manganese present in the ore concentrates in the slag phase, so that manganese is an important diagnostic element in establishing the relationship between inclusion and ore compositions.

The lime composition of the experimental slag is slightly lower than that of the furnace slag (ie 0.5% compared with 1.15%) and it is possible that this represents the absorption of lime from the charcoal, rather than reaction with the

TABLE 17

Slag Phases from Ethiopian ore 06 reduced at 1300°C – Weight %

			EDAX		
	Light Phase	**Light Phase**	**Light Phase**	**Light Phase**	**Dark Phase**
$Fe0$	87.1	83.4	85.1	81.8	46.2
$Mn0$	8.8	9.6	9.9	8.2	16.9
$Ca0$	–	–	–	–	0.3
$Si0_2$	1.8	3.4	3.1	2.7	27.0
K_20	–	–	–	–	0.9
Al_20_3	–	1.3	1.3	2.3	8.3
P_20_5	–	–	–	–	1.9
$Cu0$	–	– –	0.4	–	–
$S0_3$	–	0.6	–	–	–
	97.7	98.3	99.8	95.0	101.5
$\frac{Ca0}{Si0_2}$					0.011
			Dark phase		
$Fe0$	47.8	47.0	47.1	48.5	48.0
$Mn0$	17.4	16.1	16.3	17.1	17.0
$Ca0$	0.2	0.5	–	0.3	0.2
$Si0_2$	27.0	26.2	22.5	27.7	23.6
K_20	0.8	1.0	0.5	0.7	0.8
Al_20_3	7.5	11.2	7.8	7.2	5.5
$Ti0_2$	0.3	0.6	–	0.5	–
P_20_5	2.1	2.2	1.0	2.5	1.6
$Cu0$	–	0.3	–	0.6	–
	103.1	105.1	95.2	105.1	96.7
$\frac{Ca0}{Si0_2}$	0.007	0.019		0.011	0.009

furnace clay, since no significant damage to the furnace wall was observed, and no furnace lining was used.

Correlation of the composition of furnace slag (ie individual phases and bulk), experimental reduction products produced from a known ore composition, and inclusion phases in the Dimi iron artifacts (actual ore composition unknown)shows that the knife and digging stick are consistent with the ores of the region. The sections examined are thought to have come from a low manganese ore, such as 03 and 04, and although it is quite likely that iron produced from both types of ore could be found in the same product, this did not appear to be the case for the above items. Smelted bloomery iron was stored by the owner until such time as he required a new tool, so the products of several smelts may be collected. Ore could also be supplied by the customer as well as the smith, in which case the area of collection could have been different, and also the magnetite-containing ores could be deliberately mixed with the more limonitic ores. The complications introduced by these possibilities must always be recognized.

Discussion

The determination of the provenance of iron objects has been discussed with reference to earlier work and to the use of modern metallographic techniques, it has been emphasised that trace element analysis may not be the best approach to a study of the relationship between bloomery iron, slag and the ore source, and that the role of the minor elements, particularly in relation to the analysis of specific phases in the materials, should also be considered. The techniques of electron probe microanalysis and energy dispersive X-ray analysis have been compared and it was found that the latter was a very useful tool for rapid analysis for compositions greater than 0.5%.

Samples of Dimi iron work, furnace slag and bloomery iron have been subjected to these metallographic and analytical techniques and the compositions obtained compared with those of an experimental system. Apart from the carbon content of the iron, the experimental product of 03 at 1300°C showed remarkably good agreement with the Dimi material, and it was possible to establish that the artifacts had been manufactured from the low manganese ores. All the slag products are characerised by a low lime/silica ratio, which may be an important factor in distinguishing the Dimi ores from those of another region, and which also eliminates the deliberate addition of flux to the furnace slag.

Although Dimi iron ores were collected from sites along a mountain range twenty miles in length, the only significant composition change was the absence of manganese oxide from certain ore samples. There was no marked deviation in the primitive smelting procedure along the range, and therefore, a characteristic Dimi product would contain inclusions of low lime/silica ratio and high phosphorus content. It has been demonstrated that this phosphorus content represents the oxidation of phosphorus from the iron into the slag during forging rather than concentration of the phosphorus into the slag phase from the ore. High phosphorus inclusions should not be considered to represent the use of flux decreasing the activity of P_2O_5 and the reduction of phosphorus into the iron but are simply a consequence of the basic forging techniques applied to the artifact.

The Dimi products also have a characteristic microstructure of ferrite and low carbon bands, the position of the latter appearing to be fortuitous. Even though the work of many artisans may result in the same type of microstructure it is thought that the combination of microstructural studies with those of inclusion composition are very valuable in distinguishing the iron work of different production centres.

The presentation of results from metallographic examination

Returning to Professor Piaskowski's call for some standardisation of the form of reports and analyses, the following suggestions may assist.

A metallographic examination of an iron artifact should include descriptions and possible interpretations of the following items: –

1 Typological study of the macrostructure, where appropriate, (for example, the classification of Roman nails by Angus et al[24]).

2 The state of preservation/corrosion.

3 The variation in carbon content and microhardness of the microstructure, including any deliberate strengthening mechanisms.

4 The ferrite grain size and deduction of possible heat treatment. In view of the variation of structures within artifacts the presentation of representative microstructures at stated magnification may be most suitable, rather than quantitative measurements.

5 The inclusion morphology and composition (see later).

6 The iron composition and segregation of elements such as phosphorus, arsenic, copper, nickel and tin within the microstructure.

It is not always feasible to examine a complete microstructure, particularly in specimens required for museum display. Following the method proposed by Charles,[25] it is possible to remove a wedge-shaped piece of material with a jeweller's saw, providing two edges which can be polished and giving the structure at say, 75° to the edge, which should reveal directional characteristics. The above metallographic investigation and compositional analyses (using the electron probe microanalyser of scanning electron microscope with EDAX attachment) can be made, and the section replaced using a suitable adhesive and filler. This preserves the appearance of the artifact and provides a specimen which can be re-examined at a later date, if, for example, new techniques are available for inclusion analysis. Unlike wet chemical analysis methods, there is no permanent destruction of the removed section.

The Determination of the Provenance of Ancient Iron Objects

Metallographic studies of historical objects have so far been primarily concerned with describing the artifacts and making limited comment on the microstructure and heat treatments. The more modern metallographic techniques which have been described, combined with **in situ** studies of inclusion compositions may enable a smelting system to be more closely specified and thus deductions to be made which are of wider signficance in the consideration of:

a) The chronological development of iron smelting and fabrication processes in a particular region and the possible identification of the introduction of new techniques or external influence.

b) The establishment of links between production centres and artifacts in order to determine trade networks or possibly trace the migration of a people.

c) The relationship between the compositions of an ore, its smelting slag, the iron produced and the inclusions present in

TABLE 18

Slag phases and iron from Ethiopian ore 03 reduced at 1300°C – Weight %

(EDAX)

Fe0	36.6	37.7	36.6	37.8	38.0
Mn0	–	0.8	0.8	0.7	0.9
Ca0	0.3	0.5	0.5	0.4	0.4
$Si0_2$	33.4	35.5	35.6	34.8	33.4
K_20	–	0.2	0.2	0.3	0.1
$A1_20_3$	18.5	18.3	19.8	20.5	19.2
$Ti0_2$	6.6	6.6	6.7	7.7	6.6
P_20_5	1.1	–	–	–	–
Cu0	1.1	1.1	1.1	1.2	1.0
	97.6	100.7	101.3	103.4	99.6
$\frac{Ca0}{Si0_2}$	0.009	0.014	0.014	0.012	0.012

Fe0	38.7	38.3	38.5	67.0	Fe matrix
Mn0	0.9	0.8	0.9	0.3	P 0.317
Ca0	0.5	0.5	–	–	Cu 0.797
$Si0_2$	33.8	36.9	35.8	17.7	Si 0.264
K_20	0.2	0.2	0.1	–	
$A1_20_3$	19.4	19.8	19.9	13.5	
$Ti0_2$	7.1	7.2	7.5	5.2	Fe matrix
P_20_5	–	–	0.9	–	P 0.113
Cu0	0.7	1.1	0.5	1.0	Cu 0.832
	101.3	104.8	104.1	104.7	
$\frac{Ca0}{Si0_2}$	0.015	0.014			

the iron in an attempt to link an object to a particular type of ore and hence to a specific area. It is recognized that a production centre is not necessarily at the ore source but it is felt that such information could be valuable for many parts of Africa, where, in many cases, there is no archaeological evidence of production centres. However, metallurgical information alone will not provide complete answers to the above problems, and it must be interpreted as part of a multi-disciplinary approach.

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The manufacture of Cut Steel Studs and Beads

Rees D Rawlings

1. Introduction

Cut-steel studs and beads were widely used for jewellery and buttons (Figs. 1 and 2) as well as for decorating larger articles such as swords and scissors. The studs varied in size from approximately 1 mm to 8 mm and had polished faceted surfaces. The studs generally had shanks to facilitate assembly in the workpiece (Fig. 3). The beads were also faceted and ranged in size from about 1 mm to 5 mm (Figs. 4 and 5).

The cut-steel industry was firmly established in Britain by the seventeenth-century, expanded in the eighteenth and early nineteenth centuries and was effectively dead by the end of the nineteenth century. A concise history of cut-steel is given in Clifford's well-illustrated book on cut-steel and Berlin iron jewellery[1]. However, this book does not cover in any detail the manufacture of cut-steel and to the present author's knowledge the only article on this topic is that by Thomas Gill in 1830[2]. (This article has recently been reproduced in the Journal of the Arms and Armour Society[3]). It is known that Gill was the son of a famous sword-maker and that he was active in the Birmingham metal trade, consequently his article on the manufacture of cut-steel should be authoritative. Nevertheless, it was considered opportune to determine the accuracy of his description of the manufacturing process by carrying out a metallurgical examination of some cut-steel studs and beads.

The manufacturing process, as described by Gill, may be conveniently divided into four stages, namely (i) primary fabrication, (ii) joining of studs to shanks, (iii) carburization and (iv) shaping and polishing. This paper is concerned with the first three of these and Gill's account of these stages is as follows.

Primary fabrication: 'These steel beads and studs are formed either of well annealed sheet or hoop iron; or, which is better, of cast steel decarbonated, and which is thereby reduced to the state of the softest and purest iron, and is entirely free from the defects of the ordinary iron, such as flaws, blisters etc which are often found in articles made of common iron, after being case-hardened, but upon which, nevertheless, much expensive work had been bestowed. Some, indeed, of the more experienced workers in these steel works, select that kind of Swedish bar iron for this purpose which, on being broken, presents a shining crystallized fracture; but we should always prefer the decarbonated cast-steel.

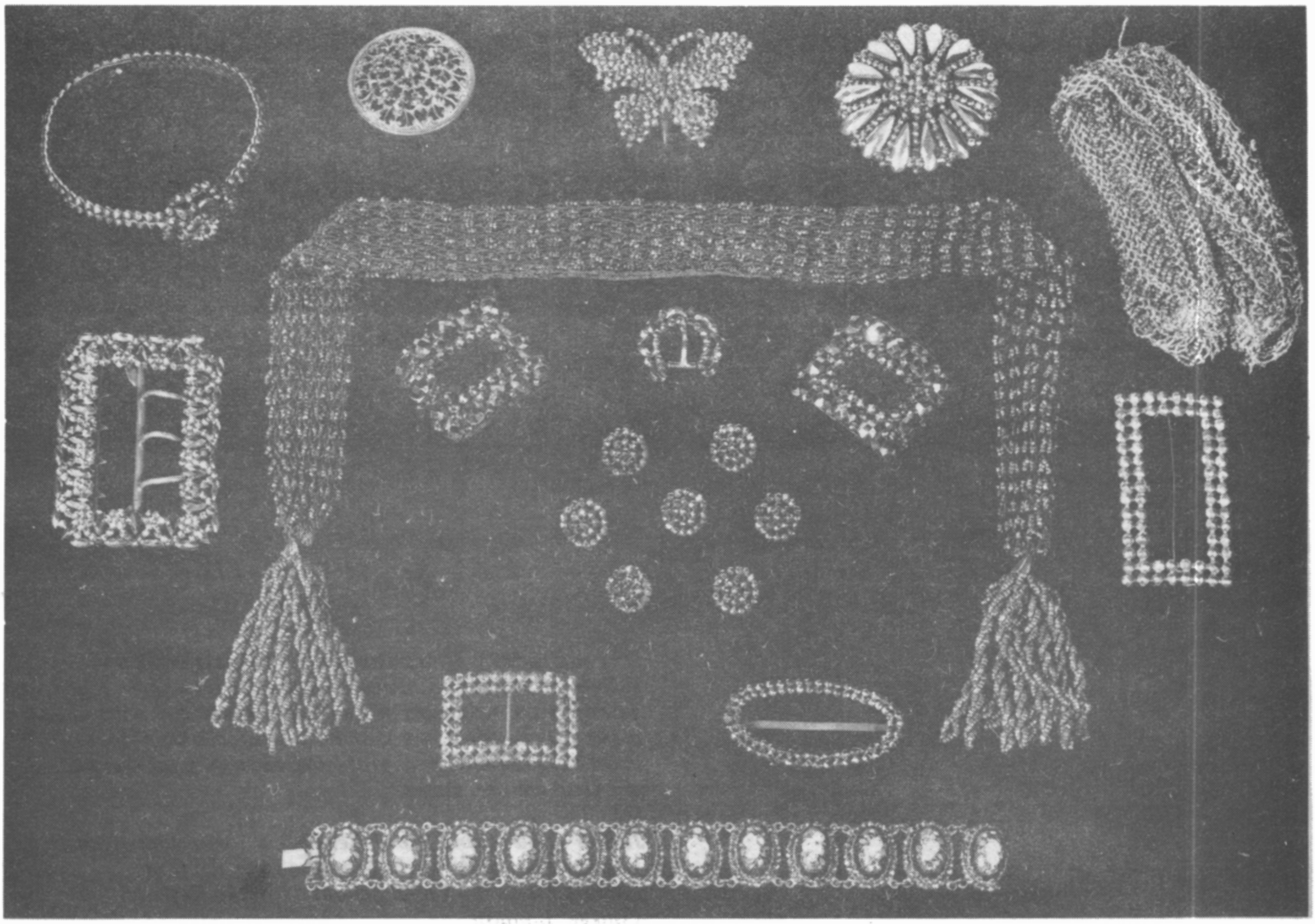

Figure 1 A selection of cut-steel jewellery.

If small steel beads are to be made, small holes are first pressed through the sheets of iron, by means of the tools termed beds and punches, used in fly-presses; and the beads are then afterwards pressed out, by other similar tools, of rather larger sizes, according to the intended beads; and the punches being also formed with slender points, to enter the holes already pressed, and with shoulders, which act in the larger holes formed in the beds; and thus they press or cut out the blanks to form the beads, with holes through the centre of each. These blanks are then shaped to the spherical form, by taking each up upon a pointed steel tool, held in a file haft, and laying it upon a hard wood filing-block, with a proper file, rounding each end of it in succession. The beads are then ready to be case-hardened, previous to their being cut into facets, both of which operations will be described hereafter.

For steel studs, whether round or oval, the blanks are to be cut out of sheet iron, by means of beds and punches, in the fly press; but no holes are made through them; instead of which, a shallow slit is cut or indented in the middle of each, by a small chisel-shaped punch, with the aid of a small hammer, and which slit is made to receive the chisel-shaped point of an iron wire, and to retain it sufficiently firm, when driven in that it may not fall out during the after process of brazing or soldering. . . ."

Joining: "... enclosing a considerable number of them in a wrapper of coarse wetted paper, together with scraps of brass, and a little borax; and then enveloping the whole in a casing of plastic clay, and leaving only a small aperture in it; when it is become sufficiently dry and hard, exposing it to the heat of a forge fire, carefully turning it about from time to time, until the fumes of the melted zinc are seen to escape through the aperture, when it must be taken out of the fire, and be rolled about upon the ground, to diffuse the brass equally amongst the studs. When cold, it must be broke open, and the wire shanks will then be found to be firmly affixed or soldered to the backs of the studs, and ready to be screwed or riveted into the different pieces, to which they are to be finally affixed, as the nature of the works may require. The faces of the round or oval studs are then to be rounded off with files, they being firmly held in pliers, by means of their shanks, during that operation."

Carburization: "They will then be ready to be case-hardened, and which operation is to be performed upon them, as in the case of the beads, previous to cutting facets upon them, the shanks, however, are to be enclosed in small masses of clay, to prevent the action of the case-hardening upon them.

This process is performed upon a considerable number of these at once, by putting them into shallow boxes or trays, made of sheet-iron, by turning up their sides at a right-angle all around, pinching the corners close, and securing them, by turning them back, and riveting them to the sides or ends. A layer of bone-dust, from which the volatile parts had been previously removed, by the distillers of ammonia, is then spread over the bottom of a box, then a layer of the studs or beads, upon which another layer of bone-dust is to be spread; then another of the beads or studs, and so on, until the tray is nearly filled, the uppermost layer being always composed of the bone-dust. The tray thus filled is then placed in a grate ordinarily formed of a few bars of iron, laid upon bricks, and with others in front, placed between loose bricks, which constitute the sides of the grate, and are generally built up within a recess or fire-place, furnished with a proper chimney, so as to afford a gentle draught, capable of maintaining a uniform red heat in the fuel, which is pit coal, as well as in the tray, and its contents, for several hours; or until the carbon in the bone-dust has performed its office of converting the iron into steel. The tray is then to be removed from the fire, and its contents, bone-dust and all, are to be thrown red-hot into cold water. The studs or beads will now be found in the state of hardened steel, with the exception of the wire-shanks in studs, which are still soft iron."

Figure 2 A gentleman in 1777 dazzles his lady friend with his cut-steel buttons (From 'Fashion' by J Dorner, published by Octopus Books Ltd. London).

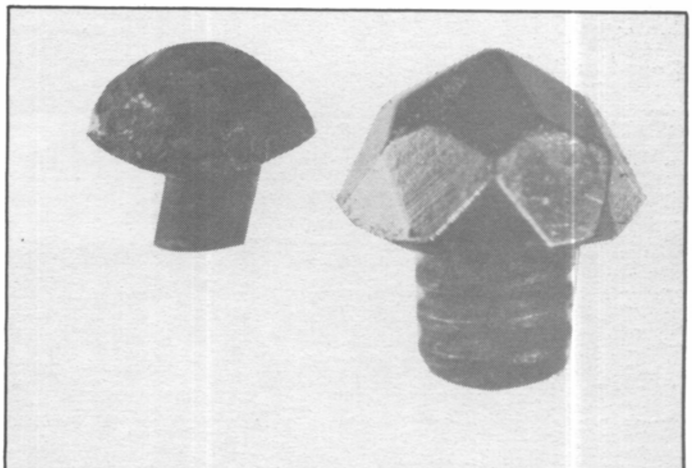

Figure 3 Studs showing rivetted and screw-threaded shanks.

2. Experimental Procedure

Metallographic examination and hardness testing were carried out on the studs and shanks of a large late 18th century button, (Fig 6) and on a smaller 19th century button, which was similar to those shown in the centre of Fig. 1. The shanks in both articles were examined in situ by preparing the backs of the articles for examination. In addition a stud, with its shank (shown on the left of Fig. 3) was removed from the large button; this was sectioned longitudinally so that both the stud and the shank could be studied. A stud with a screw-thread (shown on the right of Fig. 3), which had been removed from a chatelaine, circa 1830, was similarly sectioned and examined.

Three different beads were examined. These were i) the small bead shown in Fig. 5, ii) a similar, but slightly larger bead (2 mm diameter), taken from a 19th century long-purse, and iii) a large oval bead from a late 18th century necklace centre piece (Fig. 7). All the beads were sectioned, hardness tested and examined metallographically.

3. Results and Discussion

3.1 Studs and Shanks

It is clear from the macrograph of the sectioned stud, with the riveted shank, that the shank has been joined to the stud; the end of the shallow slit into which the shank was driven is still visible (Fig. 8A).

Solid impurities, normally sulphides or oxysulphides, called inclusions or slag are always present to varying extents in iron and steel. When the metal is fabricated into the desired shape by rolling, forging, etc the slag particles are aligned in the direction of metal flow. The shank contains aligned slag particles consistent with the shank having been cut from wire. Electron probe microanalysis showed that the slag contained mainly silicon with some calcium and traces of aluminium and potassium (sulphur and oxygen contents were not determined). The shank was not threaded and it is clear that attachment to the workpiece was by riveting, as confirmed by the upset base of the shank.

According to Gill's article the studs were joined to the shanks by 'brazing or soldering'. The essence of these processes is to introduce a film of molten filler metal between the parts to be joined at a temperature at which the parts are solid. When the melting temperature of the filler metal is above 500°C the process is brazing, when below it is termed soldering.

The thin layer of filler metal between the stud and shank is shown in the micrograph of Fig. 8B. The composition of the filler metal was determined by electron probe microanalysis to be Cu–16.5%Zn, ie. a brass. Gill reported that the studs/shanks were heated until fumes of zinc were seen; this suggests a temperature of 910°C, or slightly greater, as 910°C is the boiling point of zinc and would therefore be the temperature at which there would be a marked increase in zinc fumes. A temperature of 910°C would be sufficent to melt the high zinc (typically 40–50%Zn) brasses which are normally used for brazing. It may well be the filler metal in this case was initially of a much higher zinc content and that considerable zinc loss due to fuming occurred.

The 'little borax' mentioned in the article served as a flux, which would have enhanced the brazing by aiding the spreading of the liquid filler metal. The success of the flux

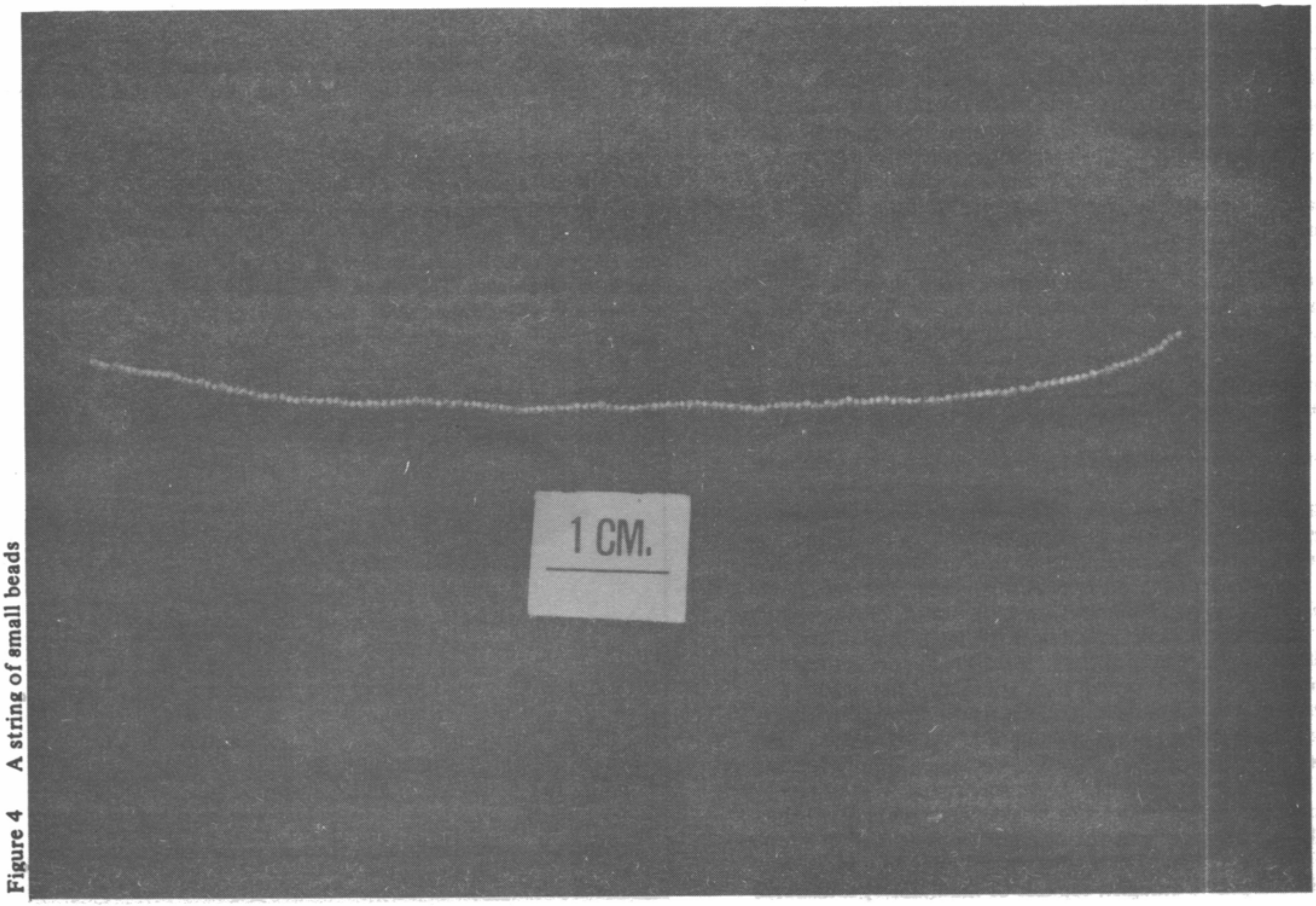

Figure 4 A string of small beads

in this respect is shown by the fact that the brass has penetrated the shank in the regions of the slag (Fig. 8C). In summary, the stud was brazed to the shank using a brass as the filler metal and borax as a flux. A similar brazing operation is still widely used today for joining small parts of mild steel.

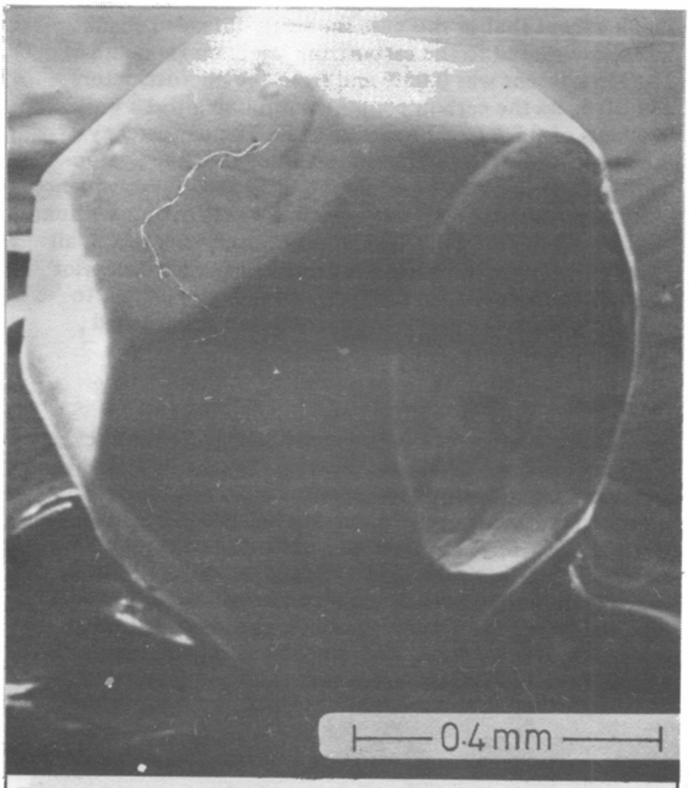

Figure 5 Scanning electron micrograph of a bead showing faceted surface and central hole. The bead was from the string illustrated in Figure 4.

Carburization is a process where by the carbon content of an iron component is increased by heating in contact with a carburizing medium at a temperature high enough for the iron to be austenitic (austenite is the high temperature phase of iron – see Fig. 9). The carburizing medium may be a solid, liquid or gas. When a solid is employed, such as the bone-dust quoted by Gill, the process is called pack carburization.

The chemistry of pack carburization is complex but the essential features of the process are, i) oxygen reacts with carbon in the carburizing medium to produce carbon monoxide (CO) gas, and ii) the CO gas decomposes at the surface of the austenitic iron to give carbon dioxide gas and carbon, which enters into the metal. Carbon on its own is a very poor carburizing agent and the carburization process is enhanced by the presence of other compounds known as energizers. Up to 20% of a modern pack carburizing compound may consist of energizers.

Bone-dust, more commonly known as bone-charcoal, is a carburizing medium which contains its own energizer, in the form of calcium carbonate (approximately 10% of bone-dust is calcium carbonate). Bone-dust has other attributes as a carburizing compound, namely that it does not shrink with use and that it retains its effectiveness without the addition of fresh material. Bone-dust was usually employed, together with long heat-treatment times, when deep carbon penetration with a relatively low (~0.8%C) carbon content at the surface were desired.

As already stated, the temperature of the carburization treatment should be such that the iron is in the austenitic condition and this requires a temperature of just over 900°C. According to Gill the carburization tray and its contents were held at uniform red heat for several hours. Table I, which is a list of colours corresponding to different temperatures, indicates that the temperature would have certainly been in the range 800-1000°C.

Table I

Temperature - Colour Relationship (Ref. 4)

Colours	**Temperature °C**
Incipient red	525
Dull red	700
Incipient cherry red	800
Cherry red	900
Clear cherry red	1000
Deep orange	1100
Clear orange	1200
White	1300
Bright white	1400
Dazzling white	1500

From the preceding discussion on the characteristics of bone-dust and the temperature of heat-treatment, it would be expected that the studs would have been carburized to a considerable depth and would have a surface carbon content of about 0.8%C. On the other hand the carbon content of the shanks would still be low as they were protected from the bone-dust by clay.

If a component in the austenitic condition is slowly cooled its structure will change to a two-phase mixture of ferrite plus iron carbide (Fig. 9). However, Gill reported that the studs and shanks were not slowly cooled, but were thrown into cold water after carburization and while still red hot. Such rapid quenching would have suppressed the transformation to ferrite plus iron carbide and instead the structure would have been transformed from the high temperature austenitic condition to martensite, which has a characteristic morphology and is hard. The microstructures of the stud and the shank are in fact martensitic (Figs. 8B and C) and thus are consistent with the component having been quenched from an elevated temperature. The stud also contains a fine crack which would have been produced during quenching by the stresses due to thermal contraction and the martensitic transformation.

The results of a microhardness traverse across the stud and through the braze into the shank are given in Figure 10. It can be seen that the hardness decreases with distance from the faceted surface of the stud and reaches a constant value in the shank of 250 HV. The hardness of quenched steels is mainly determined by the carbon content, consequently a standard graph of hardness versus carbon content (Fig. 11) may be used to estimate the carbon content of the stud and shank from the hardness values. The hardness, and the fact that the microstructure was 100% martensitic, indicated that the carbon content of the stud was about 0.6 to 0.8%C at the surface and fell to 0.3% at the brazed joint. Electron probe microanalysis showed that there was 0.08% manganese, which is a common element in iron and steel, in the stud.

The carbon content of the shank decreased with distance from the brazed joint to a constant value of approximately 0.05%. It follows that 0.05% corresponds to the initial carbon content of the wire from which the shank was made. The manganese content was found to be less than in the stud, namely 0.01%. Even though the shank was in a martensitic condition it would still have been reasonably ductile and able to be riveted. In contrast the very hard martensite of the stud is extremely brittle and profuse cracking could be induced by using a hardness tester at high loads.

The microstructures of all the shanks on the large button of Fig. 6 were martensitic and the average hardness was 239 ± 77 HV. Permanent deformation, or cold-work, at ambient temperature hardens a metal and the variation in hardness of the shanks is attributed to differing degrees of cold-work from shank to shank associated with the riveting. The shanks from the small button also had a martensitic microstructure and the average hardness was 223 ± 41 HV. It is concluded that all the shanks were made from a similar material and have received a similar heat-treatment.

Gill states that 'steel studs are secured, either by riveting or screwing their shanks into holes prepared to receive them', but he makes no specific reference to the manufacture of the studs with threaded shanks. In the author's experience the vast majority of studs were attached to the workpiece by riveting although a brief account of the production of French cut-steel only mentions screw-threaded shanks[5]. It was therefore particularly interesting to compare the studs with the two types of shank.

Unlike the previously discussed brazed stud and shank, the stud and the screw-threaded shank were made from a single piece of metal with the slag aligned along the shank axis. Some porosity was also present (Fig. 12a). The microstructure throughout the stud and the shank consisted of hard martensite and retained austenite (Fig. 12B and 13). The hardness did not vary significantly across the section and was 844 ± 16 HV. From this information it may be concluded that this component has been carburized and quenched in a similar manner to the stud with the riveted shank except that in this case the screw-threaded shank was also exposed to the carburizing medium (bone dust). The Mn content was 0.05% and from the microstructure and hardness the carbon content is estimated to be well in excess of 0.8% (see Figs. 9 and 11). The consistency of the micro-structure and hardness throughout the component, and the high carbon content, are a direct consequence of all the surfaces being exposed to the carburizing medium so allowing carbon to diffuse into the component from all directions. The screw-thread must have been present prior to heat-treatment as it would have been very difficult to cut a thread on the shank once it was in the hardened quenched condition.

3.2 Beads

The microstructure of the large oval bead from the necklace centre piece was martensitic showing that the bead had been quenched from the high temperature austenitic state. The results of a hardness trace along the line AB in Fig. 14a are given in Fig. 15. These show that diffusion of carbon has occurred from both the inside and outside of the bead, ie. the hole in the bead was present before carburization in accordance with Gill's description of the manufacture of the beads. The hardness, and hence carbon content, was less near the interior surface B (~0.3%C) compared with the

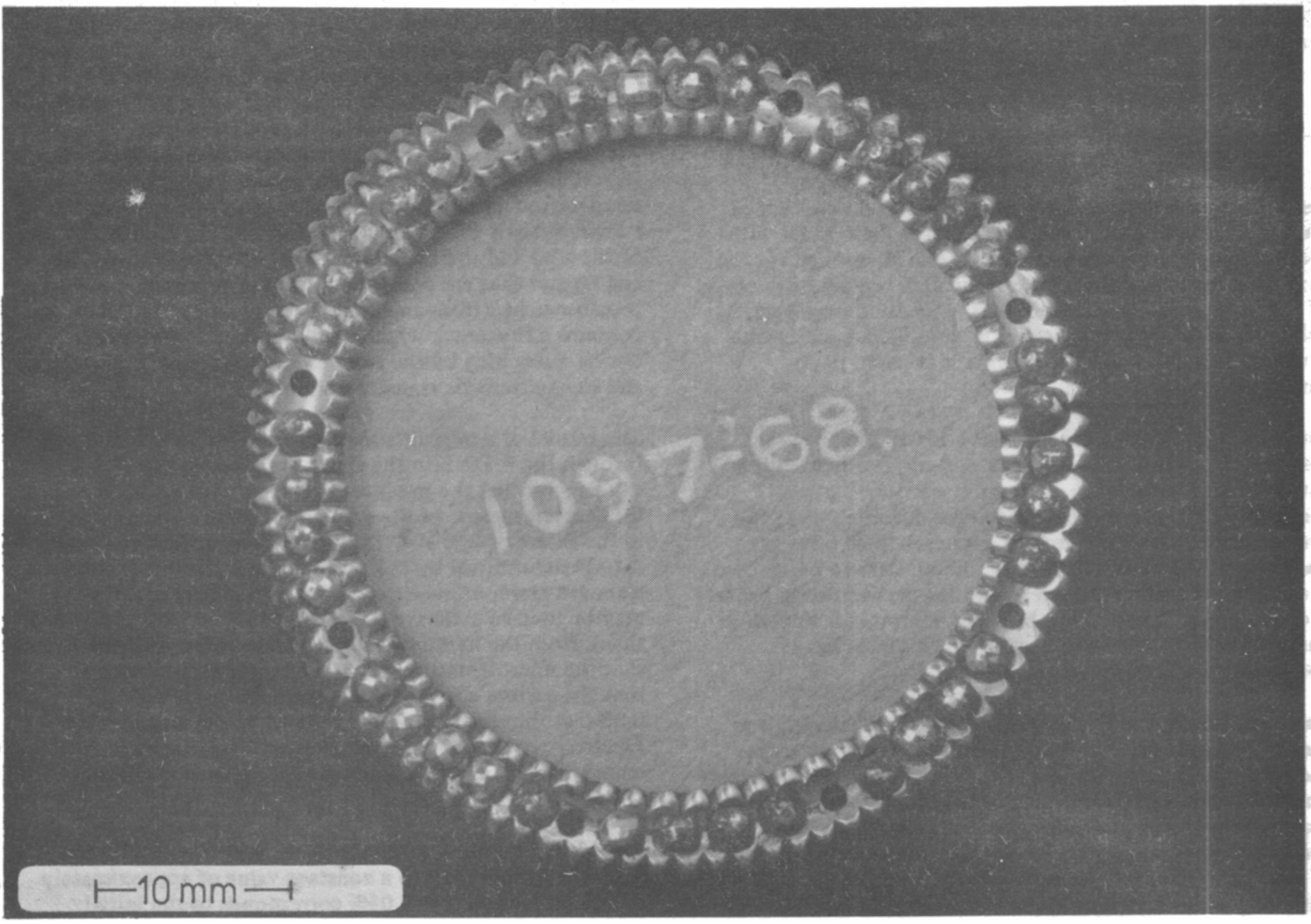

Figure 6 Large late 18th century button (incomplete).

exterior surface A (0.6–0.8%C); this indicates that the bone-dust did not completely fill the hole so leading to less efficient carburization at the interior surface.

The wire, which held the bead in position was made from low carbon content iron. The wire was still in the cold-worked ferritic condition, with a hardness of 239 ± 8 HV, and had therefore not been heat-treated with the bead. As would be expected the fabrication of the wire has aligned the slag along the wire axis (14a).

The microstructure of the bead from the long-purse was martensitic and the hardness was constant across the section at 841 ± 43 HV. Thus, it may be deduced that because the bead was small and diffusion of carbon could occur from the exterior and interior surfaces, the bead was carburized throughout to a carbon content of 0.6 to 0.8%. The direction of the punching of the hole is clearly shown by the realignment of the slag particles (Fig. 14b). The bead was poorly finished and a burr was produced on the face opposite to the blanking face, However, the direction of pressing of the bead itself could not be determined – presumably the final stage of cutting the facets and polishing removed the regions in which the slag had been realigned.

The slag was also realigned in the small bead so permitting identification of the blanking face (Fig. 14c). The microstructure was mainly martensitic but some soft ferrite was also present. The hardness did not vary over the section and was relatively low at 555 ± 17 HV indicating a low average carbon content of approximately 0.3%. The microstructure, together with the hardness value, showed that the bead was quenched from the austenite plus ferrite condition, ie. from a temperature around 800°C, rather than the fully austenitic state, ie. the heat-treatment of this bead was not completely successful because the carburizing temperature was too low (Fig. 9).

Conclusions

It was found that Gill's paper gave an accurate description of the manufacture of cut-steel studs, with riveted shanks, and beads. The only weakness in Gill's account appears to be the inadequate coverage of the manufacture of the studs with the screw-threaded shanks. From the current work it is clear that the stud and the screw-threaded shank were produced from a single piece of metal and were carburized throughout.

The carburizing and quenching procedures employed resulted in the beads and studs having martensitic, or predominately martensitic, structures of high carbon content. As a consequence the studs and beads were extremely hard and so capable of taking a good polish and remaining relatively scratch free. These were, without doubt, the reasons for carrying out such an expensive heat-treatment. However, there is an additional bonus which was probably not appreciated by the manufacturers at the time; namely, that steels in the quenched martensitic condition are more corrosion resistant than the same carbon content steel in the slowly cooled two-phase ferrite plus carbide state.

Acknowledgements

The author is indebted to Mr C Blair of the Victoria and Albert Museum and Mr J W Gooddy for their help and encouragement. The assistance of the Photographic Section of the Metallurgy and Materials Science Department is also gratefully acknowledged.

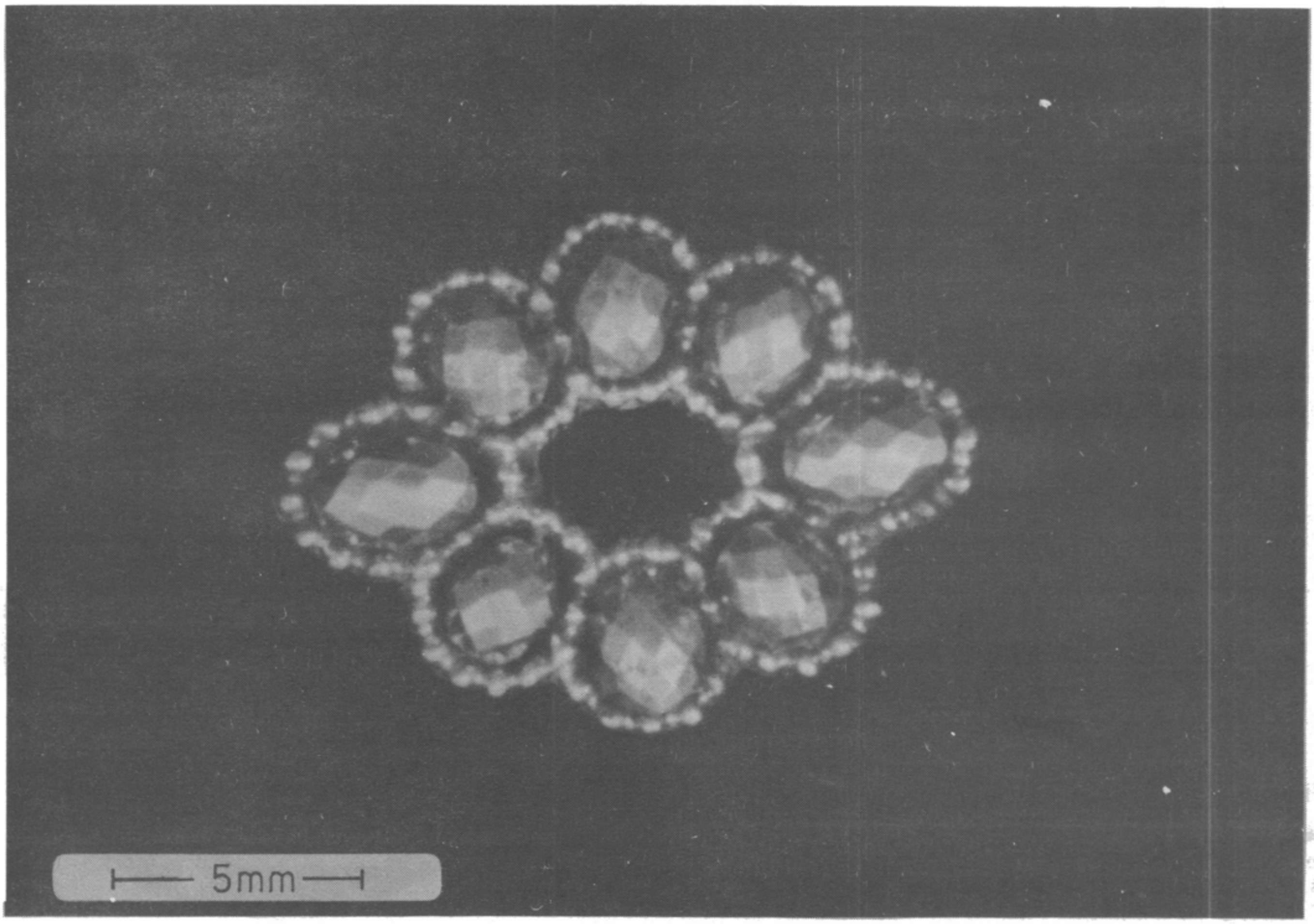

Figure 7 Late 18th century necklace centre piece.

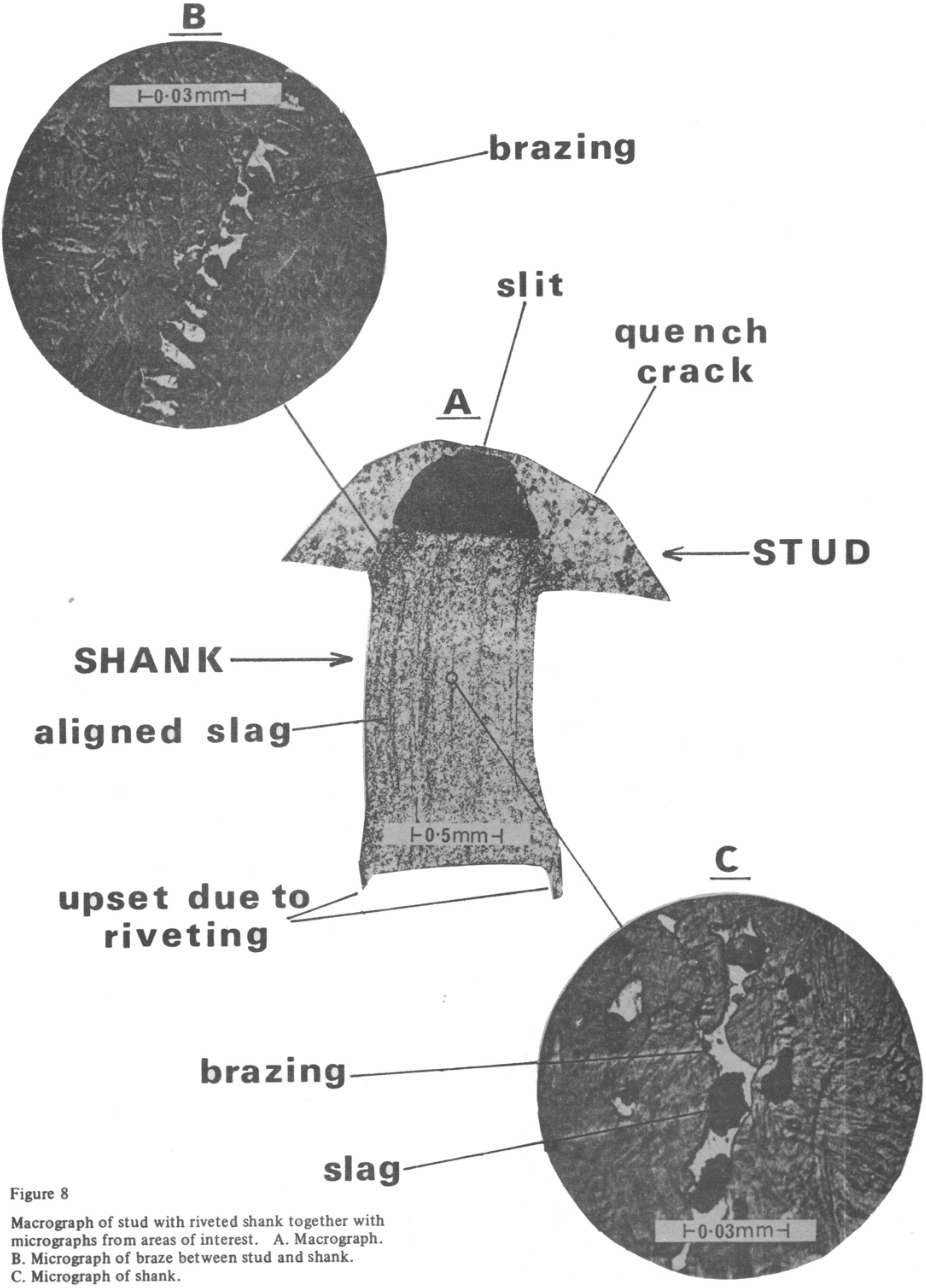

Figure 8

Macrograph of stud with riveted shank together with micrographs from areas of interest. A. Macrograph. B. Micrograph of braze between stud and shank. C. Micrograph of shank.

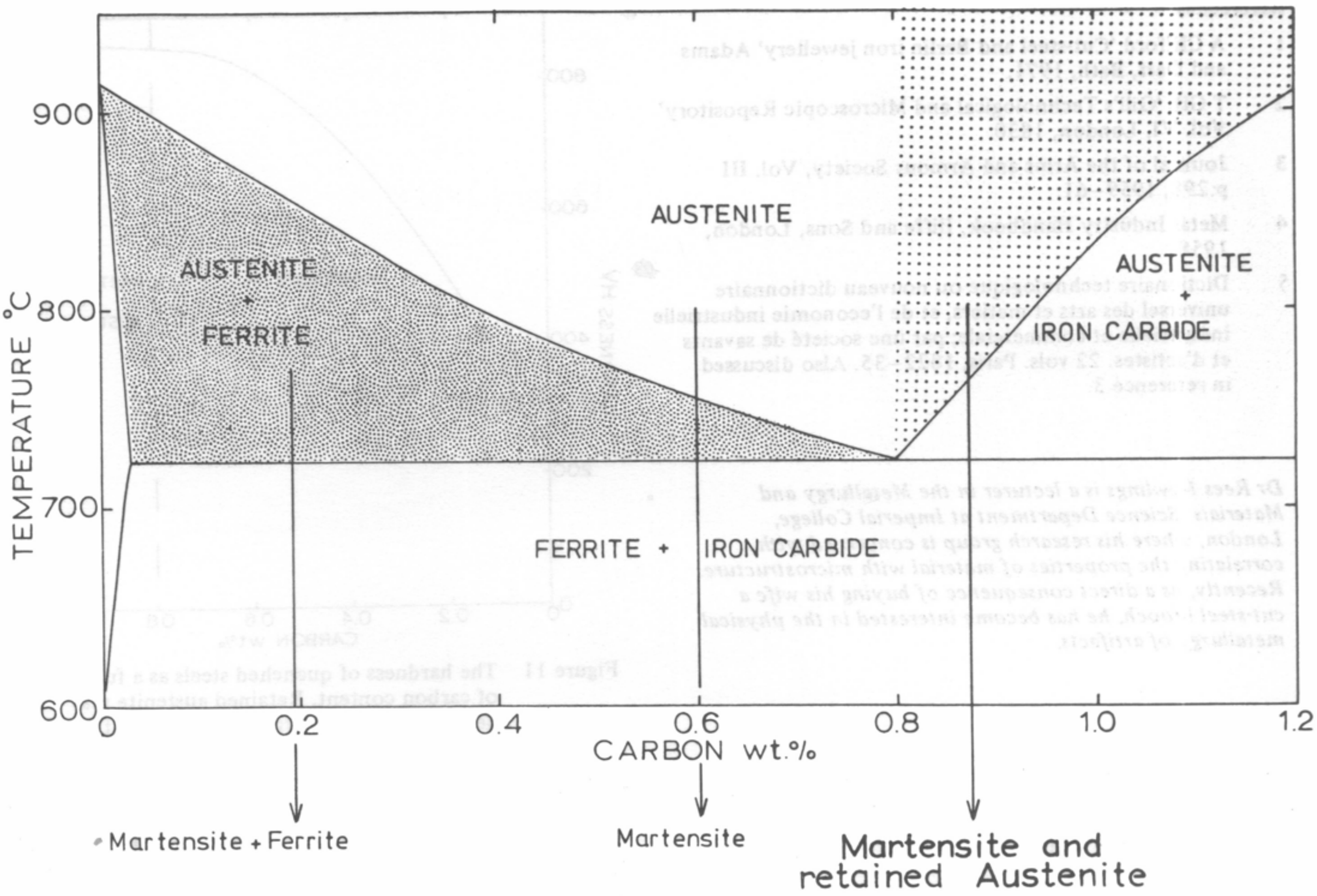

Figure 9 Diagram showing the microstructures of steel. The upper case lettering on the diagram gives the phases present under equilibrium, i.e. slow cooling/heating, conditions. The lower case lettering at the head of the arrows gives the phases produced by quenching from the phase field at the end of the arrows.

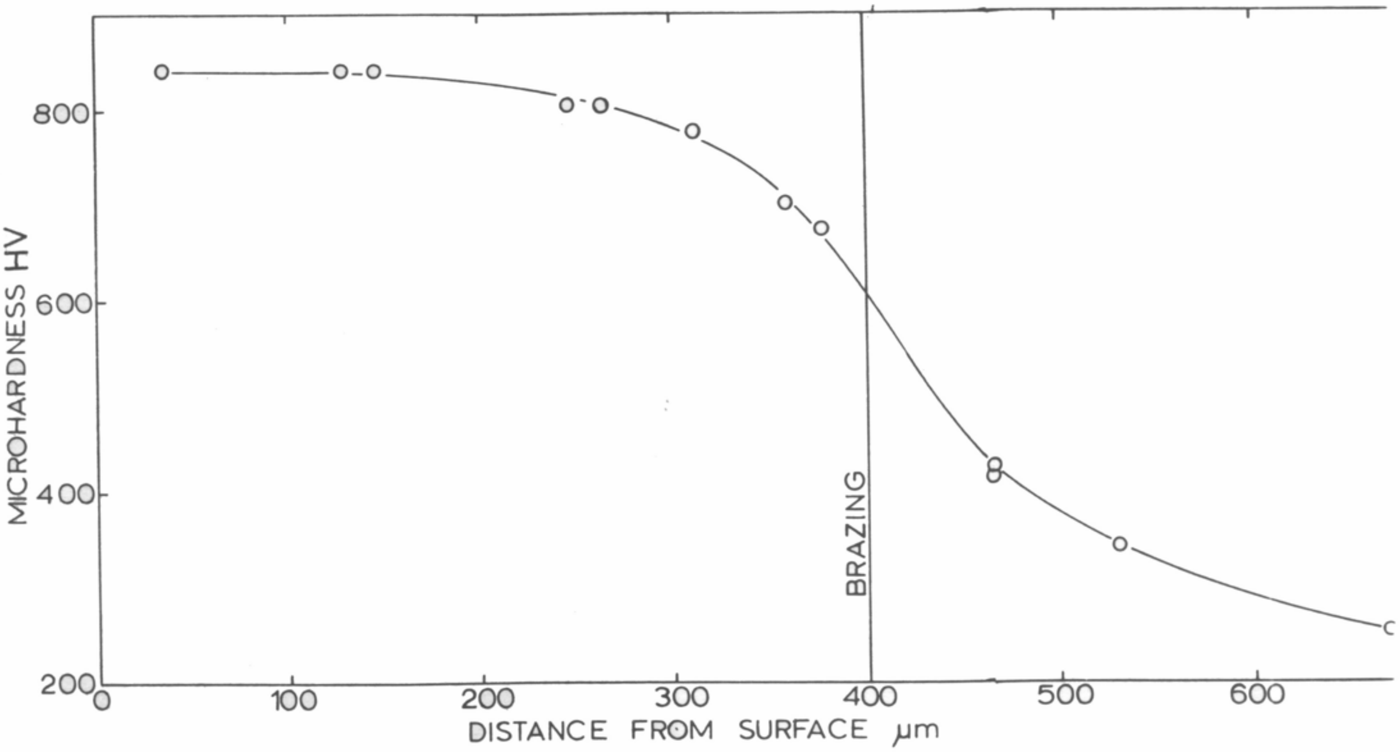

Figure 10 Hardness traverse across stud and riveted shank.

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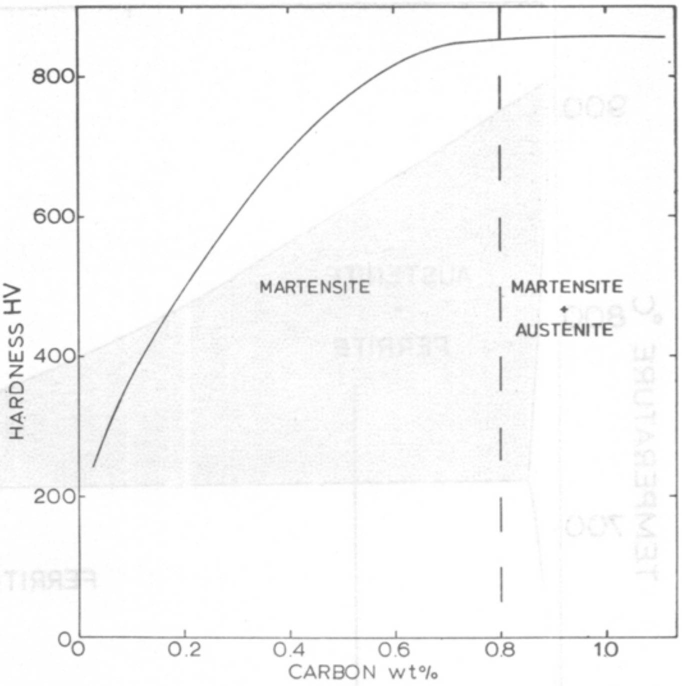

Figure 11 The hardness of quenched steels as a function of carbon content. Retained austenite may be detected by light metallography when the carbon content is in excess of about 0.8 wt%.

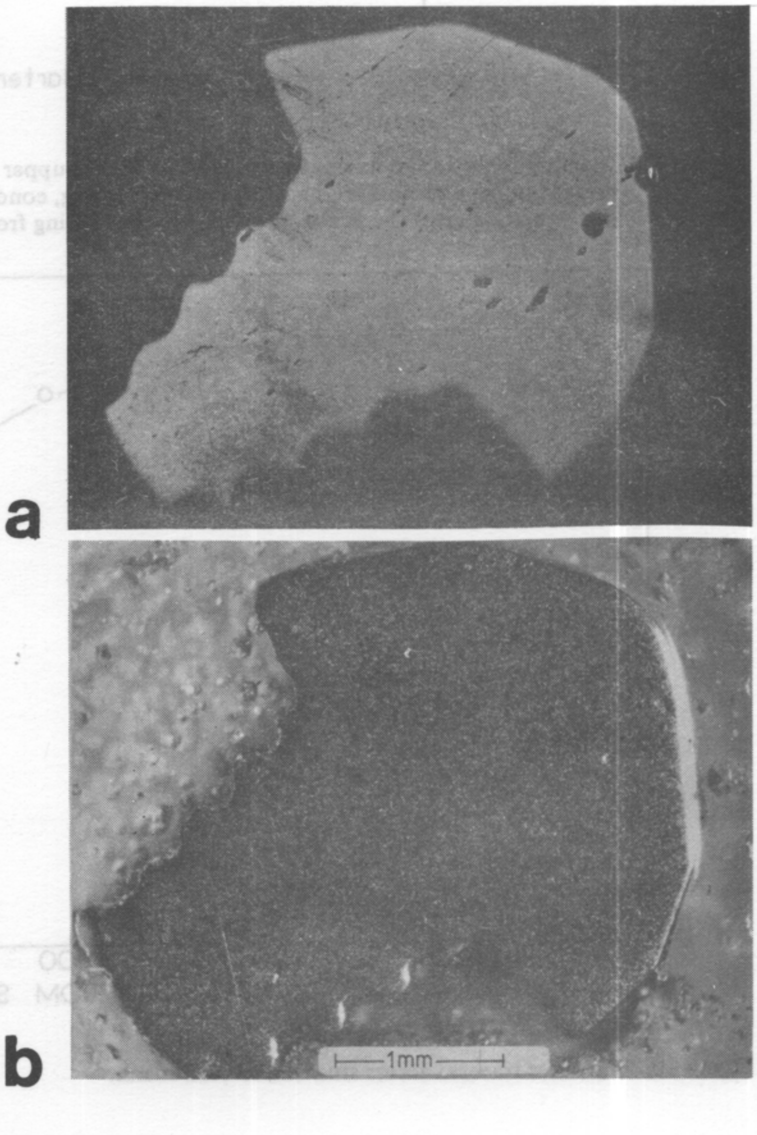

Figure 12 The stud and the screw-threaded shank were made from a single piece of metal (a) unetched showing aligned slag and porosity, (b) etched showing same microstructure throughout.

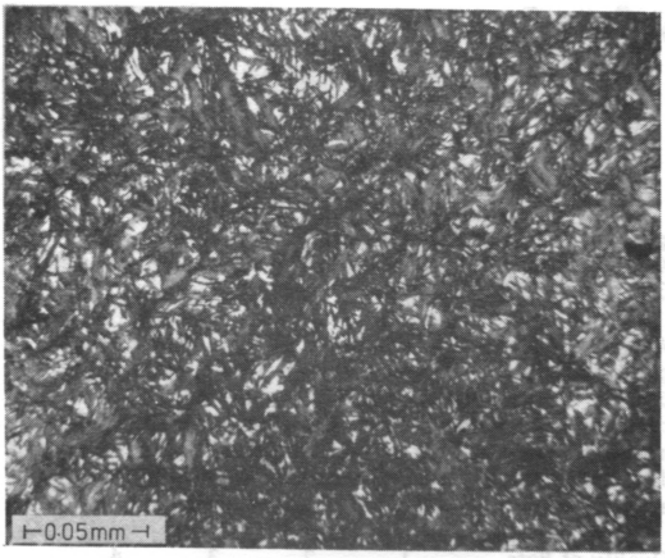

Figure 13 The microstructure of the stud and the screw-threaded shank consists of hard martensite (dark phase) and retained austenite.

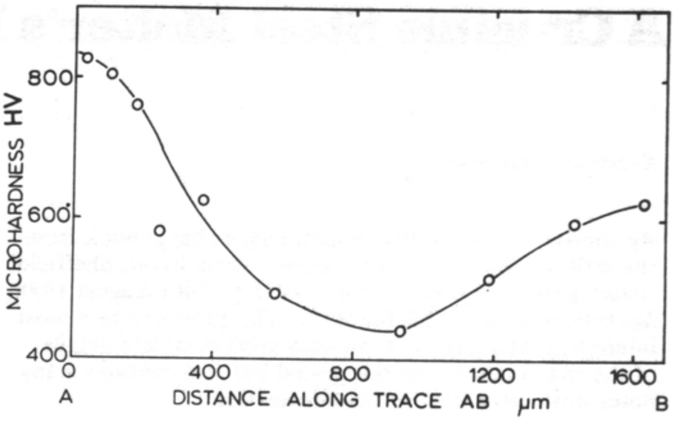

Figure 15 Microhardness traverse along the line AB in Figure 14a

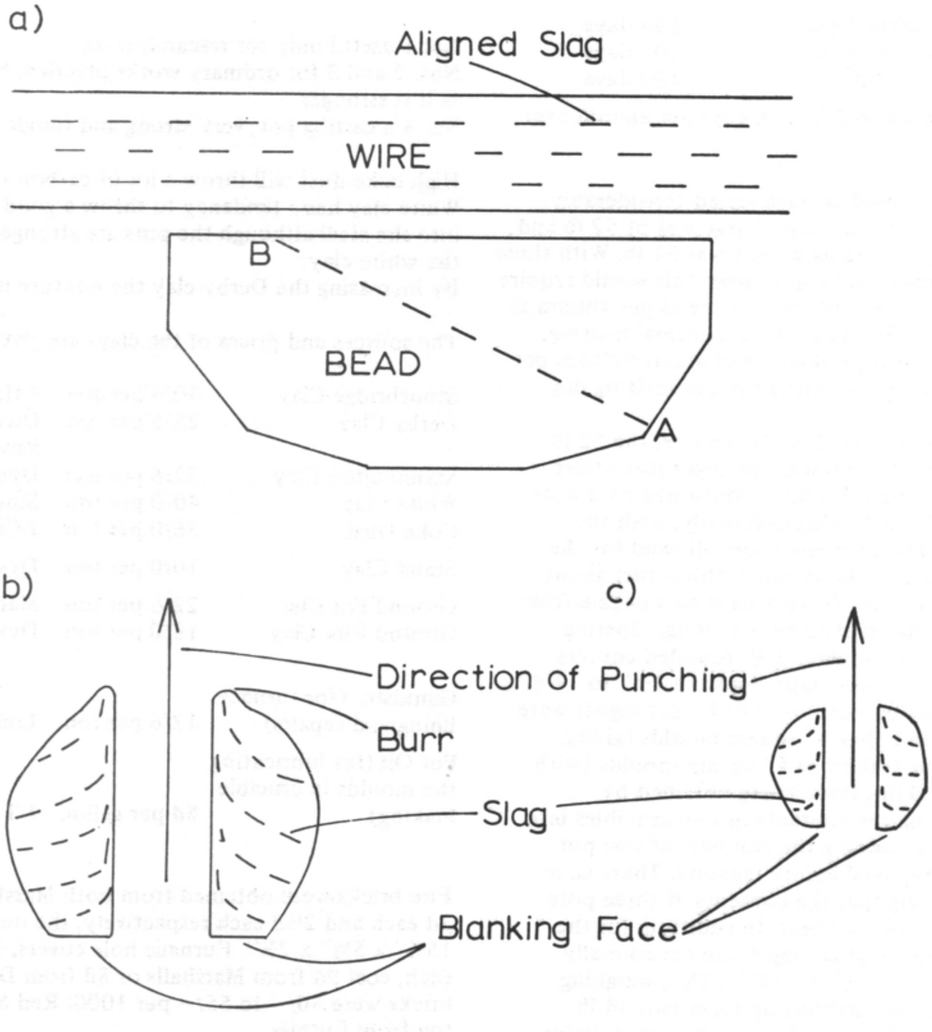

Figure 14 Sketches (not to scale) of the sectioned beads showing the alignment of slag and hardness trace AB.
a) Large oval bead from 18th century necklace centre piece.
b) Bead from a 19th century long-purse.
c) Small bead.

A Crucible Steel Melter's Logbook

Kenneth C Barraclough

By courtesy of Geoffrey H Peace, Esq, a charge book from the Wellmeadow Steel Works, Upper Allen Street, Sheffield, covering the period 8th October 1895 to 24th August 1898, has been made available for study. This proves to be a most interesting record since it not only gives complete details of the charges used over this period but also contains many notes which give most useful information.

It seems that there was a melting shop with four double-pot holes in operation. The utilisation of the melting facilities seems generally to have been on a four day per week basis; there were several variations from this, including a number of three day weeks, whilst five or even six day runs were not unknown, but there were also some completely blank weeks, not consistently at any particular period in the years covered, and so presumably connected with furnace repairs; in the main there was some activity in about 48 weeks in the year. Actual utilisation was as follows:

October 1895 to September 1896	164 days
October 1896 to September 1897	207 days
October 1897 to August 1898	150 days

giving a mean figure equivalent to 178 days per annum over the whole period.

The weights of the individual charges varied considerably from 28 lb to 66 lb. The most usual charge was of 52 lb and, in point of fact, the mean charge weight was 51 lb. With three rounds per day from four double-pot holes this would require a consumption of just under 100 tons of metal per annum as well as over 1400 crucibles a year. With a normal melting loss of around 5%, an ingot production of about 92 tons per annum is indicated – just over half a ton per melting day.

The smallest ingot size indicated is 2¾″ square; the 52 lb charge could be expected to produce an ingot just under two feet long in such a mould. This is confirmed by a note saying that the mould is 2′8″ long externally; with the thickness of the base deducted and room allowed for the 'dozzle' (or clay hot top) to be inserted, this is just about right. A sketch of the mould for making such a dozzle from clay, on the premises, shows it to be 3½″ long, tapering from 2^{3}/8″ square to 2¼″ square, with rounded corners and with a central circular hole tapering from 1¾″ to 1^{5}/8″; such a dozzle, home made only cost ¼d! Larger ingots were produced as required in either 4″ square moulds (giving ingots up to 90 or even 100 lb) or 5″ square moulds (with ingots from 100 to 120 lb), these being obtained by 'doubling up' or pouring the contents of two crucibles into one mould, generally by adding the contents of one pot to the other to mix the metal before teeming. There is, in fact, one entry indicating that the contents of three pots were used to provide a 140 lb ingot. In addition, for the production of sheet, rectangular ingots are occasionally made. One such ingot was 6½″ x 2^{3}/8″ x 18″, weighing about 80 lb, produced by doubling up from two 44 lb charges. The dozzle for this mould is also sketched, being externally 5^{7}/8″ x 2^{1}/8″, well rounded on the corners and some 5″ long; the wall was uniformly about ½″ thick. Such dozzles were purchased from Drabble and Sons and cost 18/– per 100; it is worth noting that the plug and the flask for moulding the 2¾″ dozzles only cost 14/–, made in cast iron by Oxleys. The ingot moulds cost from 7/6d to 9/0d per cwt, being obtained either from Winder Brothers or George Oxley and Sons; there was an allowance of 2/– and 3/– per cwt for old moulds.

Although it seems clear that crucibles were made on the premises (certainly the raw materials were purchased and crucible lids and stands, as well as dozzles, were made) there is no indication of flasks and plugs for their moulding, nor is there any specific 'recipe' for the clay mixture used. There is a note, however, of mixtures for clay pots 'as used at the Technical School' which is worth copying:

Quality of Pots	1	2	3	4
Stourbridge Clay	45%	40%	20%	Nil
Derby Clay	21%	17%	39%	20%
Stannington Clay	21%	17%	14%	30%
China or White Clay	10%	20%	20%	35%
Coke Dust	3%	6%	6%	15%

No. 1 useful only for research work
Nos. 2 and 3 for ordinary works practice; No. 3 preferred as it is stronger
No. 4 a casting pot; very strong and tough

High coke dust will throw a lot of carbon into the steel.
White clay has a tendency to throw a good deal of silicon into the steel although the pots are stronger by increasing the white clay.
By increasing the Derby clay the mixture is easier to tread.

The sources and prices of the clays are given:

Stourbridge Clay	30/6 per ton	J Hall and Co.
Derby Clay	28/6 per ton	Owen and Dyson or Ensor and Co.
Stannington Clay	22/6 per ton	Dysons
White Clay	40/0 per ton	Singleton Birch
Coke Dust	36/0 per ton	J Cooke
Stand Clay	10/0 per ton	Dysons or Marshalls
Ground Pot Clay	22/6 per ton	Marshalls) For making
Ground Fire Clay	15/0 per ton	Dysons) dozzles and lids
Gannister (for furnace lining and repairs)	12/6 per ton	Longdens
Pot Oil (for lubricating the moulds in crucible making)	5d per gallon	J T Dobbs

Fire bricks were obtained from both Marshalls and Dysons at 3d each and 2½d each respectively, the normal size being 15½″ x 5½″ x 2¾″. Furnace hole covers, 18½″ x 16″ x 2¾″ each, cost 9d from Marshalls or 8d from Dysons. Common bricks were 50/– to 55/– per 1000; Red Sand was 7/6d per ton from Furniss.

By far the bulk of the steel produced, as would be expected at this time, was Carbon Steel, with carbon contents ranging from 0.80% to 1.70%. The main production was for files and general tools. The domestic 'temper' scale employed in this particular works reads as follows:

X1	Millsaws only	1.70% carbon
No. 1	Sawfile	1.60%
No. 2	6" and 8" Files	1.45%
No. 3	10" and 12" Files	1.35%
No. 4	14" and 16" Files	1.30%
No. 5	18" and 20" Files	1.10 – 1.20%
No. 6	Tools	1.00%
No. 8	Tools	0.90 – 0.95%
No. 9	Tools	0.80 – 0.85%

A further more detailed list is also given for Tools:

0.80% carbon	Stamping and Minting Dies
0.90%	Cold Setts, Swages, Flatteners, Boiler Cups and Snaps, Smiths Tools
1.00%	Cold Chisels, Punches, Table Blade Steel Circular Saws
1.15%	Taps, Screwing Dies, Reamers
1.20 – 1.25%	File Cutters, Patent Axle Steel, Mill Picks, Extra Large Turning Tools, Pen and Pocket Blades
1.35 – 1.40%	Turning, Planing and Slotting Tools, Hard Lathe Tools and Razors.

The tool steels were generally produced using some proportion of blister steel bar, which was purchased from Doncasters. This according to grade of Swedish iron used cost from £8.15.0 to £19.10.0 per ton; none of the premier grade irons were used, however. For the rest, internal scrap was utilised where appropriate, together with cheaper Bessemer or Siemens scrap (at £2.10.0 to £3.10.0 per ton) and some Swedish iron ('Box Ends'). Every charge was carefully calculated on the basis of the required carbon content, any carbon deficiency generally being made up by the use of Swedish white cast iron (with about 4% carbon), although almost every heat contained in addition from 2 to 6 ounces of charcoal. The carbon recovery from this was calculated as being 80%. The charcoal, incidentally, was supplied by Shirley Aldred at 8d per bushel. The overall utilisation of Swedish materials, including the blister bar, the bar iron, box ends and the white iron would appear to have been in the region of 25–30% of the total material melted.

It seems clear that, as usual in a small works, the material was checked by the appearance of the fracture; we have comments such as 'came out too mild' or 'came out A3, wrong calculation for A2'. Again after such comments we sometimes read on subsequent charges 'added 2 oz charcoal for rust', indicating that rusty scrap had given some decarburisation.

Some chemical analysis was carried out, but it is clear that this was the exception. One charge for saw ingots, aimed at 1.10% carbon has the comment: 'These came out at 0.98% – had one analysed. They certainly were a good ingot. In future, I must calculate them 1.20 and then they will come 1.10, as I find they usually drop a little'. Another charge 'came 0.85% carbon – too mild'. Again, checking six ingots, intended for 'best penknife quality' with 1.20% carbon, these came out 1.09%, 1.05%, 1.15%, 1.20%, 1.17% and 0.95%, the second and sixth ingots being graded as 'Temper 6' and transferred to other uses. Two similar ingots were analysed a few weeks later, both coming 1.11% carbon; the next check came out at 1.16%. 'Best penknife blade quality', therefore, seems to have had some importance. Certainly it was made almost entirely from Swedish material; the ingot cost was about 16/6d per cwt, 6/6d of this being the melting cost and 10/0 the material cost. The melting cost in 1895–96 had been less, being quoted as 5/9d per cwt for 'ordinary' steel and 6/0d per cwt for 'tool' steel. At this time coke was obtained for 19/6d per ton. At the beginning of 1897, however, the price was increased to 22/0d per ton and the melting costs were increased by 6d per cwt, since 2¾ tons of coke were needed to melt one ton of steel. Prior to this, a cheap melt using Bessemer scrap as the main part of the charge could be produced for less than £9.0.0 per ingot ton!

The use of 'alloys' is rare. By no means every cast is treated with manganese. This would appear to have been unusual since it was common practice in Sheffield to make additions of spiegeleisen and there is no mention of this alloy in the records. Some casts do have an addition of ferromanganese, but only to the extent of 0.10 – 0.20% manganese addition. The ferromanganese used contained 7% carbon and 80–84% manganese and cost £13 to £16 per ton. The use of aluminium is implied rather than confirmed; there are references to some charges carrying '1 oz ferromanganese but no aluminium'; prices of aluminium from various sources are quoted, from 1/5d to 2/6d per lb (£160 to £280 per ton).

The addition of chromium to a few charges, producing a material with about 1.45% carbon and 1.25% chromium, destined for 'special wire', appears from August 1897 onwards; the ferrochromium used contained 60–64% chromium and 8% carbon and cost 1/0d per lb.

The most interesting adventure into alloy steel, however, consisted in various attempts made from May 1897 onwards to produce 'Self Hard Steel' – no doubt in an effort to copy the Osborn–Mushet material which at this time had been produced in Sheffield for some twenty years to the secret recipe worked out by R F Mushet in the Forest of Dean. The 'desired' analysis quoted is as follows:

C	Si	Mn	W	Cr
1.8%	0.6%	1.8%	10.0%	1.0%

The first cast was made 18th May 1897, using a ferrosilicon with 1% carbon and 10% silicon (at 5/0d per cwt), 96% tungsten powder at 2/0d per lb and ferromanganese and ferrochromium as mentioned above. The charge details were as follows:

		Carbon			
7 lb	Swedish White Iron	4.0%	28.0	@ 5/9	4¼d
15 lb	Swedish Box Ends	0.9%	13.5	@ 8/0	1/1d
12 lb	Swedish Blister Bar	1.0%	12.0	@ 10/0	1/0¾d
6 lb	Nails	Nil	Nil	@ 4/6	2¾d
2.5 lb	Ferrosilicon	1.0%	2.5	@ 4/6	1d
1.12 lb	Ferromanganese	7.0%	7.8	@ 15/0	2d
0.83 lb	Ferrochromium	8.0%	6.6	@ 1/0*	10d
5.25 lb	Tungsten	Nil	Nil	@ 2/0*	10/6d
4 oz	Charcoal	80.0%	20.0		½d
49.70 lb	@ 1.8%C 90.0		90.4		14/4d
	Cost of material per cwt				32/9d
	Melting cost per cwt				6/6d
	TOTAL				39/3d

* These figures are per lb; the others per cwt.

A further two melts were made on 15th October 1897, with a similar charge, but aiming at 1.20% chromium. (A week later a melt of Magnet Steel, with 0.8% carbon and 3% tungsten was made). Four more melts of 'Self Hard' followed on 27th October 1897; the first three were of 42 lb each, whilst the fourth had an addition of 10 lb of Self Hard scrap. The tungsten powder had now gone up to 2/3d per lb and there is a pencil comment that it will be 2/9d per lb in future.

The next attempt at 'Self Hard' was two ingots made on 9th March 1898, but using a ferrotungsten with, allegedly, 4% carbon and 40% tungsten; this melt was analysed and gave only 4.62% tungsten, the silicon content being very high at around 2%. There is a comment: 'evidently the tungsten is wrong in the ferrotungsten'. Thus even at a cost of 1/1¼d per lb the ferrotungsten proved more expensive than the tungsten powder.

It is significant that the next two ingots, made 4th April 1898 refer back to their being 'as 27th October 1897' and are made by reverting back to tungsten powder, but incorporating 25% 'Self Hard' scrap. Subsequently we find a note for a melt on 11th May, 1898: '1 ingot Self Hard from same as March 9th' and again, on 24th May, 1898: '1 ingot Self Hard from Blackwell's Alloy, using more ferrotungsten to get the tungsten up.'. This may imply that the earlier heat that month was a 'wrong-un' since the theoretical tungsten addition in this case was 12% rather than 10%. This line was taken further; on 16th June 1898 another cast was made with ferrotungsten, with a theoretical tungsten of 30% being given to the ferrotungsten and all ferrosilicon being omitted to counteract the high silicon in the tungsten alloy. This again does not seem to have been successful, since on 27th June 1898 we have four casts made with tungsten powder, now at 4/9d per lb. There our saga is, presumably, cut short by the book running out of pages, but it is of interest to list the costs per cwt for this series of Self Hard ingots:

28.5.97	39/3d
15.10.97	40/6d
27.10.97	43/10d
9.3.98	46/6d
4.4.98	not quoted
11.5.98	not quoted
24.5.98	50/0d
16.6.98	52/10d
27.6.98	68/10d

It would seem that inflation was not unknown even in those days! It is worth noting that the cost of the 96% tungsten powder rose from 2/0d to 4/9d in just over a year (£224 to £532 per ton); the prices of the other alloys, however, remained constant over this period and it could just be that, with the growing interest in 'Self Hard', as evidenced by such trials in a relatively small works, the demand for tungsten was growing fairly rapidly and the rise in price was a reflection of this demand.

This record book, therefore, gives a considerable amount of interesting information relevant to the time when alloy steel was in its infancy. It is probably typical of what was going on in many similar small establishments in Sheffield at the period when most of the large producers of steel had moved on to the use of bulk steelmaking processes for the larger forgings and mass production methods of rolling. Most of them, however, retained some crucible shops and the pattern in these shops cannot have been much different either; they may have used slightly larger crucibles and some of them had changed over to gas firing rather than coke firing; some of them were using plumbago pots,* which lasted many more heats and which could be prefired and then transported, thus precluding the necessity for pot-making on the premises. There, quite clearly, however, we have the continuation of the tradition founded by Huntsman some 150 years earlier and it has been a privelege to be allowed to study this most valuable document and to endeavour to interpret some of the intriguing information contained in it. One final point of interest is that many of the suppliers at the end of the nineteenth century are still well-known names in Sheffield steelmaking circles.

POSTSCRIPT

By a curious coincidence, a record of experimental crucible steel casts made at River Don Works over the period 1903–1923 has just come to light. This is a beautiful leather-bound volume with 'CRUCIBLE STEEL 2' 'V.S.&M. Ltd'* in gold on the spine, with pages ruled for the entry of the intended analysis, the mixture used, the analysis obtained and, where thought necessary, remarks. Unfortunately, the book has suffered from damp and the writing on the edges of some pages has been obliterated. Nevertheless it provides some very interesting information on the development of alloy steel.

Many aspects are covered, particularly related to the development of nickel-chromium and other low alloy steels, principally for bullet proof plates; the peculiar interest in the present context is to follow the steps in the development of 'High Speed steel' from 'Self Hard' and this can be traced in the experimental work arranged by a firm which was in the forefront of the developments in Sheffield, as may be evidenced by their trials of the 0.3%C–13%Cr cutlery steels within a year of their discovery by Brearley – rather intriguingly in trials of bullet proof plates!

Three variants of 'Self Hard' itself are included in the trial casts; their analyses are all rather different from the Wellmeadow Works analyses:

		C	Mn	W	Cr	
1903		1.7	0.4	8.0	3.5	
1906	A	2.0	0.5	8.0	1.2	'forged well: impossible to cut
	B	1.5	1.5	5.8	2.5	

By the beginning of 1903, however, the term 'High Speed steel' was being used. It will probably be remembered that Taylor and White in America in 1901 had begun to talk of such a material and, in point of fact, in 1907 the River Don records have a cast made to 'Taylor's analysis' as given in 'Iron Age'. This was 0.67% carbon, 18.9% tungsten and 5.47% chromium.

The 'High Speed steel' which held supreme position for about fifty years was the so-called 18/4/1 (18% tungsten, 4% chromium, 1% vanadium with 0.7–0.8% carbon). This finally appears in 1915–1916 and the following list shows the gradual move towards this composition:

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*People using these learned to cope with the carbon increment. In general this was only severe on the first melt and therefore could be allowed for. Bearing in mind that such pots would give a service life of 10 to 15 melts (or even more in isolated cases) this was not an impossible situation. Attempts were made to have the best of both worlds with a composite pot – plumbago outside with a clay lining – but this seems to have been a passing phase.

	C	W	Cr	V	
1903 High Speed Steel	0.65	11.3	2.0	. . .	
do.	0.7	12.5	3.5	. . .	
H.S.N.	0.7	18.0	2.8	. . .	'To imitate Novo' **
1904 H.S.T.	0.6	18.0	3.5	. . .	'Superior to Novo on all tests
1905 H.S.M.	0.65	14.0	5.1	. . .	'Osborn Mushet'
H.S.C.	0.5	13.0	3.0	. . .	'Seebohm's Capital'
1907 H.S.3 with V	0.6	18.0	3.0	0.3	
	0.5	13.5	4.9		'Beardshaws'
1908	0.57	18.0	2.65	0.75	'Novo Superior'
1910 H.S.3P	0.68	18.68	3.27	0.85	VSM Twisted Drill
1915	0.70	15.80	4.30	1.21	'Triumph Superb'
	(A Jessop brand, also containing 1.2% cobalt)				
AE 105	0.70	18.00	4.25	1.30	(Fully developed 18/4/1 composition)
1921 S.B.S.T.	0.80	18.80	4.12	1.72	'Gave most excellent results under test'

Further modifications of the analysis occur, mainly in the addition of cobalt, up to 6% and molybdenum, up to 6% also. One most interesting forerunner of modern practice is a cast with 6% molybdenum but no tungsten, unfortunately there is no comment on its results.

* Vickers, Son and Maxim, Limited

** Trade mark of Jonas and Colver Limited

The beginning of the Wireworks at Whitebrook, Gwent, in the early 17th century

D G Tucker

The wireworks at Whitebrook, about 8 km south of Monmouth on the west bank of the river Wye, were started in the very early 17th century as a branch of the then-prospering Tintern wireworks, already established for about four decades. The latter were the first works in Britain to use water power for drawing iron wire, and were thus the first to be able to produce wire of a quality comparable with that of European production. The works at Whitebrook were similarly based on water power. The Society of Mineral and Battery Works was responsible for these enterprises, and much has been written about this important monopoly set up during Elizabeth's reign.[1-4] However, until recently, little has been done to establish the physical nature of the works,[5] and in the case of Whitebrook not even the approximate locations and extent of the ground occupied seem to have been determined until my own recent investigation.[6] Since publishing the paper quoted, I have, thanks to a suggestion by Mr H W Paar, been able to find the basic deed[7] by which the land at Whitebrook was leased to the Society by the Earl of Pembroke. This is a most important document. By itself, at the present day, being devoid of plans, it would hardly be adequate to define the land occupied; but as a result of my previous work I have been able to interpret it and determine the boundaries of the land with some confidence. A number of other interesting matters also arise from the deed.

Date of occupation of the land by the wireworks

An especially important matter which the deed settles is that of the date of occupation of the land by the wireworks and the beginning of the construction of the works. There has previously been doubt on this matter. The Court Books (or minute books) of the Society for the period around the end of the 16th and beginning of the 17th century appear to have been lost, although earlier and later volumes are available at the British Library. From later references[8,9] it was known that there was a deed of 1607 referring to land granted to the Society at Whitebrook, and Schubert[10] assumed that this was the date at which the Society started activities at Whitebrook; however, Rees considered the commencement to have been before 1600.[11]

The deed now located is certainly dated 6 June 1607, but it is made quite clear that the Society had occupied the land since the previous Michaelmas and had already constructed some works, notably two leats ('newe diches') and some buildings ('newe workehowses'). It thus seems that the date of commencement at Whitebrook was September 1606, beyond any reasonable doubt.

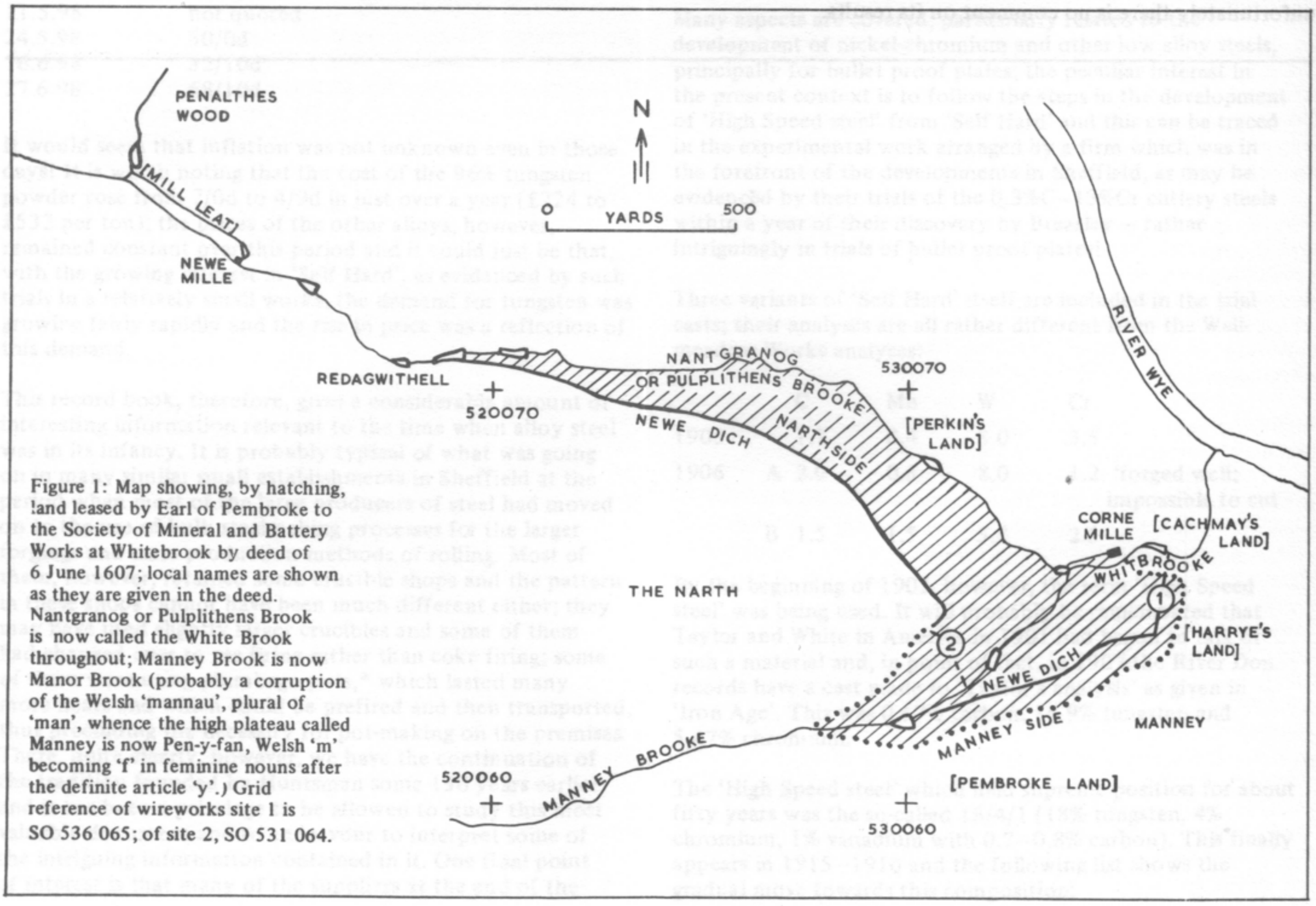

Figure 1: Map showing, by hatching, land leased by Earl of Pembroke to the Society of Mineral and Battery Works at Whitebrook by deed of 6 June 1607; local names are shown as they are given in the deed. Nantgranog or Pulplithens Brook is now called the White Brook throughout; Manney Brook is now Manor Brook (probably a corruption of the Welsh 'mannau', plural of 'man', whence the high plateau called Manney is now Pen-y-fan, Welsh 'm' becoming 'f' in feminine nouns after the definite article 'y'.) Grid reference of wireworks site 1 is SO 536 065; of site 2, SO 531 064.

Boundaries of wireworks land

The lease gives rights to the Society over all the streams which join the White Brook, but the land to be occupied is more limited. It is shown hatched in my map of Fig.1. In this map the stream nowadays called the White Brook is shown with the embanked ponds which can now be located, but there is no evidence as to which of these, if any, existed in 1606–7. The stream defines the northern boundary of the wireworks land and the long leat the southern boundary of the north-west tongue, but there is the interesting provision that the Society may use land up to one perch (about 5 m) outside these boundaries for the purposes of making dams, ponds, etc., for their works. The stream still flows, and the leat can still be traced on the ground, so these boundaries are definite.

On the south and east the boundaries are less well-defined. John Aram's survey[12] of the Manor of Trellech made in 1772 shows the boundaries from the end of the long leat to the south side of the Manney Brook, and although his map was made half-a-century after the wireworks closed, this boundary is probably quite reliable. But south of the shorter leat, and to the east, the boundary is not certain. According to the deed the total area should be about 80 acres; according to Fig.1 it slightly exceeds 90. Possibly the surveyors of 1606–7 could have been in error by this much, and certainly we cannot remove as much as 10 acres from the hatched area in Fig.1 without departing from the boundaries as defined in the deed. Probably, therefore, Fig.1 is reasonably correct.

Sites of 'workehowses'

In my previous paper I suggested that there were probably five sites occupied by various units of the wireworks, and indicated the locations and gave a full discussion of my evidence and reasoning. It is very disappointing that only one site of 'workehowses' is specifically mentioned in the deed. This is marked '1' inside a circle on the map of Fig.1. This site agrees well with my previous work, which was, in respect of this site, based on field evidence. I feel quite confident in suggesting that there must also have been a site at the point marked '2', because the leat leads there. It runs at an elevation of 140 m, over 48 m above the shorter southern leat, and would hardly have been constructed merely to feed the latter. As now existing it is a large leat, about 2 m wide, whereas the southern leat is a small one of about one-third this width. At the site '2' there are, moreover, some levelled areas on the steep hillside and the remains of some buildings. It is possible, however, that the works on this site were not completed until much later.

The other sites I suggested were on the main brook, called Nantgranog in the deed in its upper reaches, and these seem to be provided for in the deed by the inclusion of the right to build ponds and dams on this brook, intruding if necessary up to one perch into the land to the north of the brook. Possibly these sites were not brought into use until the wireworks expanded in the second quarter of the 17th century following the abandonment by the Society, and the transfer to other operators, of the works at Tintern.

The deed includes provision for the Society to build cottages for its workers on this land, and for the tenants to have both the privileges and obligations normal in the Manor of Trellech.

REFERENCES

1 William Rees, 'Industry Before the Industrial Revolution', Cardiff, 1968

2 M B Donald, 'Elizabethan Monopolies', Edinburgh, 1961

3 H Hamilton, 'The English Brass and Copper Industries to 1800', London 1926.

4 H R Schubert, 'History of the British Iron and Steel Industry', London 1957.

5 H W Paar and D G Tucker, 'The old wireworks and ironworks of the Angidy Valley at Tintern, Gwent', J Hist.Met.Soc., 1975, **9**, 1–14.

6 D G Tucker, 'The seventeenth-century wireworks sites at Whitebrook, Monmouthshire', Bull.Hist.Met.Gp., 1973, 7(1), pp.28–35.

7 Gwent County Record Office, 4806 (M446). I have prepared a full transcript of this deed, and can make xerox copies available at cost.

8 Court Books of Society of Mineral and Battery Works, Brit.Lib., Loan 16, Vol.3.

9 Foley Papers, Hereford County Record Office, F/VI/Af/18.

10 Loc.cit., pp.294–5.

11 Loc.cit., p.628

12 National Library of Wales.

A Copper smelting furnace at Hissarcikki, near Ankara,

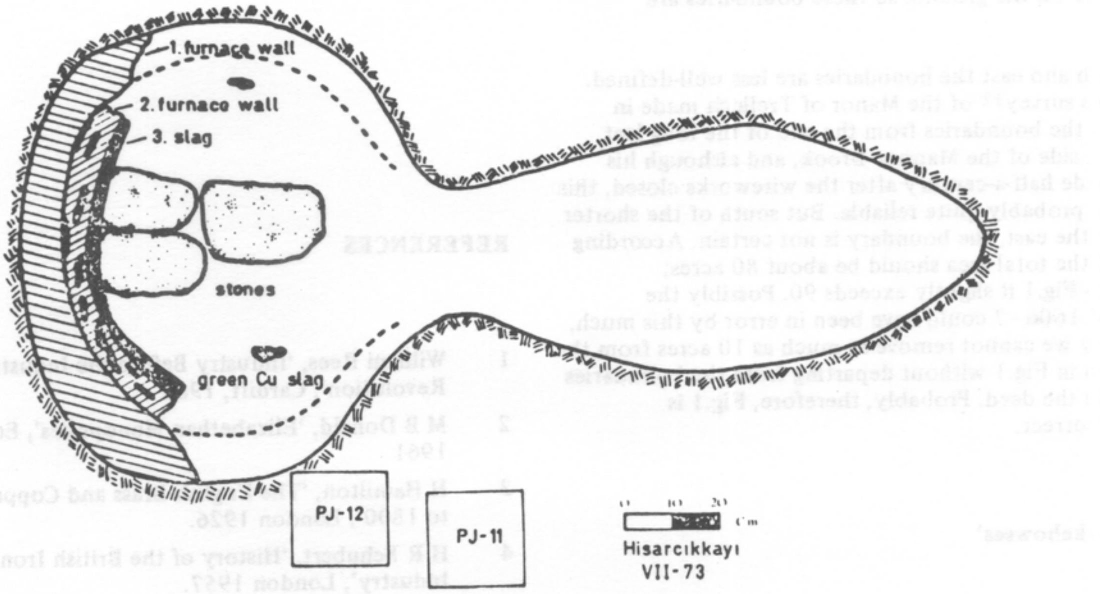

Figure 1 Top view of furnace

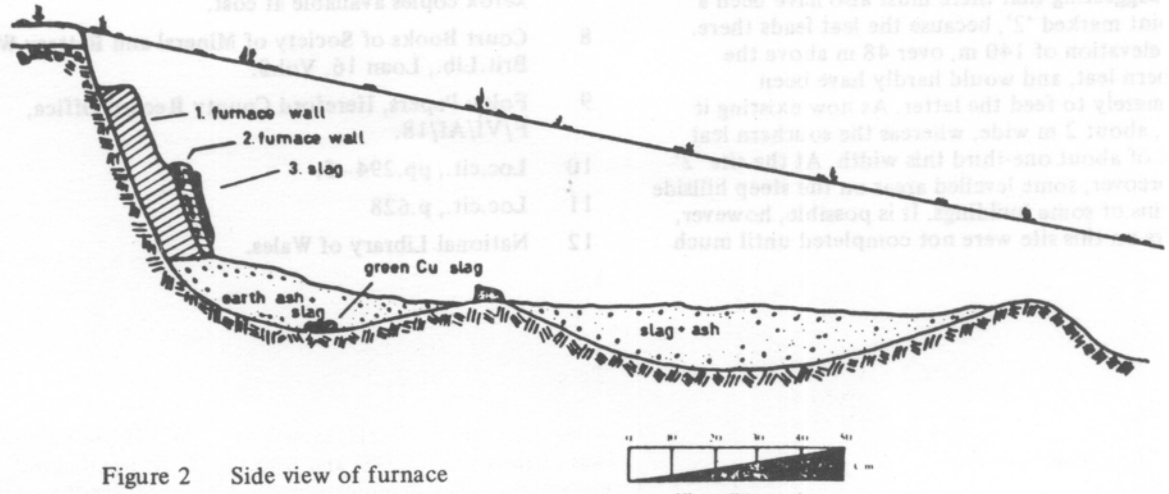

Figure 2 Side view of furnace

Turkey

by Prentiss S de Jesus

Prentiss S de Jesus is now at the Institute of Archaeology, London. He was formerly Director of the American School of Archaeology in Ankara, Turkey.

In 1973 and 1974 the author accompanied MTA[1] personnel into the field in an effort to study ancient mining and smelting complexes and to locate ancient sources of tin ore. The furnace described below was discovered in the course of this investigation.

Hissarcikkayi is a village located on the east flank of the Eldivan Mountains and west of the Kalecik-Çankiri road. As the crow flies it is about 90 kms northeast of Ankara. West of the village on the right bank of the Sari Göz stream there are slag dumps scattered over about 100 m². Sherds can also be found in the general area. Near the stream we located the remains of a furnace (Figures 1–3) used in ancient smelting operations. Prior to MTA's visit the furnace had been broken open by a villager, and a stone slab (Figures 4 and 5) was removed from its bottom. Due to its ruined state we were unable to determine the exact size and shape of the original structure, but a proposed reconstruction has been published.[2]

The furnace is small (see Figures 1 and 2), the interior being on the order of one metre in diameter. It had been built into the slope of the hill which is composed of a crumbly conglomerate. The latter constituted the surface upon which an unlevigated mortar was applied for the first furnace wall. We were unable to determine what the wall was like above the surface of the ground. A shallow depression in front of the furnace (Figures 1 and 2) may have been a tapping pit, but this is not certain, for none of the slag we saw showed signs of flow. The successive firings of the furnace (later determined as matting operations) had left slag layers on the mortar lining. Also, parts of the lining had broken away, for repairs are evident. In some cases extra mortar had been applied over the slag slayer, and in other cases stones were used to plug gaps in the wall. This appears to have been done in an almost haphazard fashion perhaps because of the unimportance of a carefully applied lining or because it may have been difficult to work on the lining from the outside.

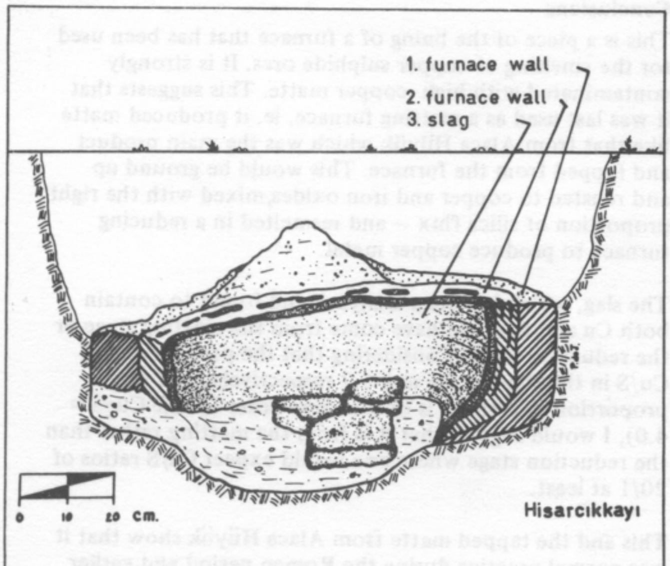

Figure 3 Front view of furnace

In any case, it was evident that successive firings of the furnace were succeeded by repairs. The last time the furnace was used its interior volume had been reduced by at least 30%. Slagcoated walls must have been detrimental to the matting operation, and the smelters applied successive mortar linings so as to have slag-free surfaces.

We are uncertain as to the exact position of the stone slab (Figures 4 and 5). There are traces of slag on only one side, particularly near the shallow channel on one end (arrow in Fig 5). The shape of the slab suggests that it may have been adapted to different furnaces at different times.

Analyses of the slag and furnace remains (see Tylecote's report in Appendix) provided some unique data. Two analyses of the slag in the area of the furnace gave the following results (%):–

Cu	0.91	3.11
Sn	nd	nd
Pb	0.003	0.003
As	nd	nd
Sb	nd	nd
Ag	nd	0.0007
Bi	nd	nd
Au	nd	nd
Zn	0.80	0.49
Ca	0.03	0.03
Fe	40.94	27.39
S	0.14	0.55

nd = not detected

As pointed out in Tylecote's report the ratio of Cu/S suggests a matting slag as opposed to a reducing slag where the Cu/S ratio would be much higher. Hence, this furnace appears to have been used to produce enriched copper matte from a copper sulphide ore. The reducing furnace must be located somewhere on the site, in which case future research there would be worthwhile.

The large trace of Zn indicates to a certain extent the ore type exploited. Further revelation came when a greenish-blue slag (Figure 6), located a few hundred metres from the furnace) was investigated. Analysis gave the following constituents(%):–

Cu	0.30
Pb	0.04
Ag	0.0002
Zn	>10
Co	0.002
Fe	>1.0

A second analysis of this material showed that the Zn content was of the order of 80% and S was 1.7%. As pointed out elsewhere[2] this slag indicates some kind of separating phase where the ancient smelter was trying to extract copper from some kind of polymetallic mineral rich in Zn. It is possible that sphalerite (Zinc blend, ZnS) was the main unwanted mineral. The high Zn in the matting slag also points to a

Zn-Cu relationship in the original ore body. Bachmann has detected a similar case in the Hittite slags from Alaca Hoyuk.[3]

Two samples were taken of the furnace wall and through the kind permission of MTA were sent to the Oxford Research Laboratory for Archaeology for archaeomagnetic determination. Dr M Barbetti took charge of the dating. Preliminary results suggested a date of Late Roman, which coincides with our interpretation of the site. The archaeo-magnetic data has been filed with the General Directorate of MTA for future reference.

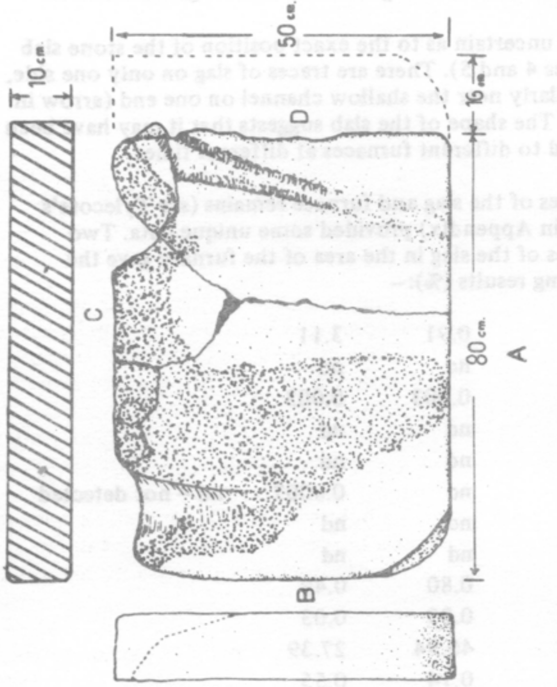

Figure 4 Stone slab from bottom of furnace.

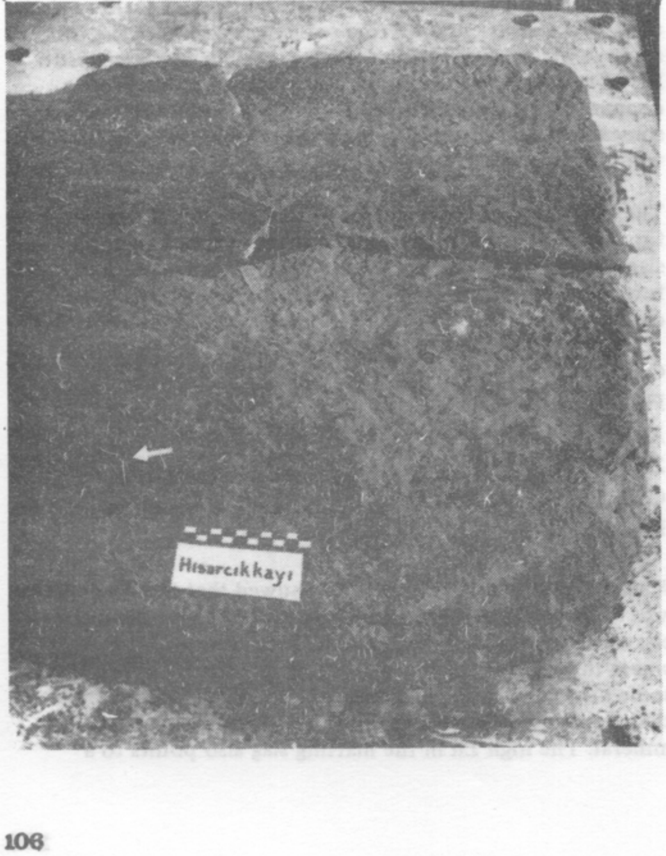

Figure 5 Stone slab from bottom of furnace

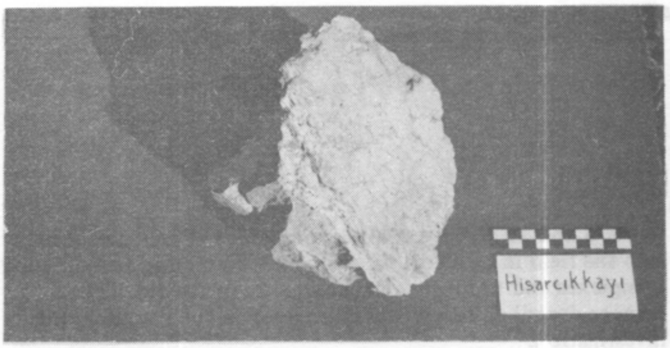

Figure 6 Zinc slag.

APPENDIX

Report on Hissarcikkayi Furnace Lining *by R F Tylecote*

The piece of lining received was about 2.5 cm thick. The internal surface was red and friable, and proved non-magnetic. The other surface was much darker and denser but was still reddish. It was slightly magnetic. This material was very uniform in composition and consisted mainly of lathy or star-shaped silicate crystals in a glassy matrix with spherical blow holes. It also contained some spherical inclusions of a copper-rich matte (mixed sulphides). Near the internal surface there was a good deal of matte which had copper coloured grain boundaries and cracks filled with a grey phase. This matte had a 'widmanstatten' structure with one phase precipitated on the octahedral planes of the other. A hardness impression gave a figure of 100 HV5.

The structure and hardness are very like a piece of tapped matte that I have examined from Alaca Hüyük and which I obtained from the museum there in 1973. This type of matte is usually termed 'blue metal' and consists of a light matrix with the widmanstatten precipitation of a blue phase. It contains some metallic copper like that from Cankiri and has a hardness of 62-102 HV.

Between the dense slag and the metallic constituent was a single area of denser reddish material which proved to be completely amorphous but which is probably a denser form of the inner friable material. The friable red material also had bluish sulphide spheres but was otherwise featureless.

Conclusions

This is a piece of the lining of a furnace that has been used for the smelting of copper sulphide ores. It is strongly contaminated with high copper matte. This suggests that it was last used as a matting furnace, ie. it produced matte like that from Alaca Hüyük which was the main product and tapped from the furnace. This would be ground up and roasted to copper and iron oxides, mixed with the right proportion of silica flux – and resmelted in a reducing furnace to produce copper metal.

The slag, which has been analysed and found to contain both Cu and S, could have come from the matting stage or the reduction stage. Considering that the proportions of Cu/S in the slag are 6.5 and 5.7 respectively, and the proportion in a matte is of the same order (100% Cu_2S = 4.0), I would suggest that it is from the matting rather than the reduction stage where one would expect Cu/S ratios of 20/1 at least.

This and the tapped matte from Alaca Hüyük show that it was normal practice during the Roman period and earlier to smelt sulphide ores using the traditional matting process rather than oxidizing the minerals directly and reducing them.

Acknowledgements

The author wishes to express his thanks to the Director of MTA, Dr Sadrettin Alpan, for permission to publish the information contained in this article and for the full support he has given to research on ancient metallurgical problems in Turkey. The author also wishes to acknowledge the contributions made by Ergun Kaptan, Ertan Toykuru and Suna Tonger of MTA, Dr Michael Barbetti of the Oxford Research Laboratory for Archaeology and the History of Art, and Dr Ron Tylecote of the University of Newcastle-upon-Tyne. The author also wishes to thank the American Research Institute in Turkey (ARIT) for the financial support received during his stay in Turkey.

Notes

1 Maden Tetkik ve Arama Enstitüsü (= Turkish Mineral Research and Exploration Institute) of Ankara.

2 P S de Jesus, 'Metallurgical Practices in Early Anatolia,' Bulletin of the Mineral Research and Exploration Institute of Turkey 87, 1977, pp. 53–4, figure 1.

3 H – G Bachmann, 'Untersuchungen an vor-und frühgeschichtlichen Kupferverhuttungs-Schlacken,' Zeitschrifte für Erzbergbau und Metallhuttenwesen Bd. XX, Heft 9, 1968, pp.420–1.

The analyses of two Roman mirrors from Nijmegen

Whilst engaged on research into Roman Mirrors in the Rijksmuseum G M Kam, Nijmegen in the Netherlands, the writer discovered a hand written letter, wrapped about fragments of two mirrors. It was addressed to Mr Kam, who founded the museum in order to house his extensive collection of Roman antiquities. As very few of the older reports of analyses can be correlated with mirrors that are still extant, a free translation of the letter, from the transcript made by Miss Maia van Vloten, has been prepared for its historical and scientific interest.

Dr H L Visser,
Laboratory for Chemical and Microscopic Research
Nijmegen, 8 February 1912.

Dear Mr Kam,
Here are the analyses of the two types of old Roman mirror metal, that I received from you. One fragment had a light reflecting surface, the other fragment a much darker, glassy but inferior reflecting surface.

The alloy, from which both metals were made, is composed of copper, lead and tin, but in different proportions. Further, there were small traces of contamination present in the metal, but nothing that had been added intentionally. It now seems to me that the white metal is not silvered, as we had previously thought.

Darker metal	tin	:	23%
	lead	:	8.5%
	copper	:	66.8%
Lighter metal	tin	:	20.1%
	lead	:	14.4%
	copper	:	63.5% "

The fragments of the mirrors that Dr Visser had not needed for his analyses were compared with the incomplete mirrors and fragments in the rest of the Kam collection. It was discovered that the darker fragments belonged to mirror no. XXI. f/Gc.2, and the lighter fragments to mirror no.. XXI.f/Ga.7. These are both small hand mirror types. The latter is plain apart from light spin marks on the back, and has a diameter of ca. 8.1 cm. The former piece is similar, with the addition of a light series of dot-and-circle patterns spaced at intervals as a border to the reflecting side. It has a diameter of ca. 12.2 cm. Both pieces probably had a simple loop shaped handle.

The group to which they belong is particularly interesting, as most of the pieces are closely dated to the Flavian period with a few examples, heirlooms perhaps, coming from early second century burials.* The majority of the pieces, some 40% of the total, have been found in the Lower Rhine area, with a thin spread out into adjacent areas of East Anglia (27%), Belgium and the upper reaches of the Rhine. It seems highly probable that these pieces are the produce of one particular workshop operating during the second half of the first century. Nijmegen, where 23% of the mirrors of this type has been found seems the most likely centre, and it can only be hoped that fresh analyses will be undertaken in the not too distant future, using modern techniques, to cast further light on the composition of these interesting Roman provincial bronzes.

G Lloyd-Morgan,
Grosvenor Museum, Chester.

*Dated examples include two pieces from Bliquy, de Laet et al. La Necropole Galloromaine de Bliquy (Bruges 1972), Grave 49, p. 73, 88, pl. 18, Grave 335, p. 72, 126, pl. 94; from Maastricht, Belfort Grave 2–51, Bogaers,

Nieuws Bulletin van de Koninklike Nederlandse Oudheidkundige Bond, 17, (1964), p. 63–6, 105–9, 138–9.

Notes

Comite pour la Siderurgie Ancienne: Ten Years of Activity.

The year 1977 reminds us of the ten years' existence of the Comité pour la siderurgie ancienne which started its activity one year after the establishment of the group by the General Assembly of the International Union of Prehistoric and Protohistoric Sciences at the occasion of the VIIth Congress of the UISPP, Prague 1966. The original idea was to concentrate all scholars who were interested and actively working in the field of the earliest common history of iron so as to secure a forum and means of information on the research and the respective results in terms of international and interdisciplinary cooperation.

Up to the present day 165 corresponding members from 22 countries from all over the world have been registered – archaeologists, historians of technology, metallurgists, technicians, chemists, miners, economists, and the like. All these scientific fields can make use of the data relating to the development of one of the most important branches of production which always has been exerting a deep influence on civilization in different parts of our world.

We are glad that the management of the Archaeological Institute of the Czechoslovak Academy of Sciences represented by Professor *J Poulik*, who simultaneously is one of the three obligatory members of the Conseil Permanent of the UISPP, are ready to house the Comité at Prague and to offer the necessary help (administration, translations, distribution, etc. for which we are deeply indebted to Mmes *R Fabesova* and *H Ticha*) as well as to take care for editing the communications on the pages of the Institute's journal Archeologicke rozhledy. We still are one of the few groups who do not ask their members for any fees.

The biannual communications are the main form of our work. The reader is given current information and surveys on conferences and symposia dealing with the history of iron technology, on exhibitions, excavations, laboratory research, etc., and abstracts of the published results: the bibliography lists not only specialized papers and books which are devoted to the theme but it brings excerpts of important news from other literature as well (excavated features, analyses, important comments). Unfortunately, it is hardly possible to fully exhaust all the materials so that we take the liberty to invite all corresponding members and friends to make us acquainted with any information they could.

830 bibliographical items have been registered up to now. The number is rather significant when considering our specialized and interdisciplinary field of work. The individual themes are represented as follows: excavations of bloomeries, blacksmith's workshops, reconnaissances 26%, metallographical investigation of archaeological iron 20%, notes on important iron objects occurring in archaeological sources (including artefacts of chronological and technological importance) 15%, general studies and discussions on the history and economy of iron in different geographical areas 13%, analytical methods and results excepting metallography 7%, smelting experiments and theory of the bloomery process 5%, hoards of ironwork 4%, mining iron ore 2%.

The Comité cooperates with various centres and institutions, eg. Museum of Archaeology at Cracow, University at Kharkov, Institute of Archaeology at Moscow, Kwartalnik Historii Nauki i Techniki at Warsaw, Geschichtsausschuss des Vereins der deutschen Eisenhuttenleute at Dusseldorf, specialized groups organized by the Jarnkontoret, Stockholm, Revue de l'histoire des mines et de metallurgie, Basel–Paris, and many others. The most successful cooperation is practised with the revue Historical Metallurgy, London with whom we exchange manuscripts of bibliographies so that the missing data can be added undelayed.

Moreover, the Comite encourages consultations among members, and two specialized colloquiums or symposiums were organized. In 1970 at Schaffhausen, Switzerland, it was entitled "Die Versuchsschmelzen und ihre Bedeutung fur die Metallurgie des Eisens und dessen Geschichte" attended by 12 specialists in trial smelts from 10 European countries; in 1975 at Eisenstadt, Austria, the colloquium was entitled "Archaeologische Eisenforschung in Europa, mit besonderer Berucksichtigung der Eisengewinnung und Verhuttung in Burgenland", where 15 reading participants from 8 European countries were present.

The president and the secretary hope that the future activity of the Comité pour la sidérurgie ancienne will steadily provide useful help to anyone who is interested in the study of the early history of iron.

W U Guyan – R Pleiner

Center for Materials Research in Archaeology and Ethnology

The National Endowment for the Humanities of the USA has awarded two grants totalling $350,000 over three years to the Center for Materials Research in Archaeology and Ethnology (CMRAE), a new Center established by nine educational, research, and cultural institutions in the Boston area.

CMRAE is a major undertaking whose purpose is to encourage a new direction for research in anthropology, archaeology, art, history, and related humanistic and social science disciplines by providing them with an expanded technical base in the sciences of organic and inorganic materials. The NEH grants will be supplemented by contributions from participating institutions, private foundations and individuals.

Participating institutions are Boston University, Brandeis University, Harvard University, the University of Massachusetts, Massachusetts Institute of Technology, Museum of Fine Arts of Boston, Robert S Peabody Foundation for Archaeology, Tufts University, and Wellesley College. MIT has agreed to serve as the Center's coordinating institution and as such will handle administrative matters for the Center.

Heather N Lechtman is Center director in addition to maintaining her present responsibilities as associate professor of archaeology and ancient technology in the MIT Departments of Humanities and of Materials Science and

Engineering. Her background is in the fields of anthropology, archaeology, art history, physics, and the conservation of archaeological artifacts.

The research program of the Center will emphasize rigorous laboratory study of artifacts and other kinds of cultural remains in order to determine the nature and structure of the materials of which they are composed and the extraction and processing regimes they have undergone. The Center hopes to sustain a level of in-house research that will generate new insights into the ways in which societies have interacted with the material world and eventually to make its facilities and trained personnel available to scholars from non-Center institutions to assist them with their own investigations.

A primary goal of the Center is the establishment of education and training programs to increase the number of those extremely rare scholars who are capable of formulating research problems on the basis of a dual competence in a humanistic or social science discipline and in a physical or biological science. Scholars from non-Center institutions and/or their graduate students with a base in the humanities and social sciences will be encouraged to join the Center's laboratories on a visiting basis to work on their own materials while becoming acquainted with the properties of those materials and with the specialized techniques of the relevant materials science disciplines.

One of the primary tasks of the three-year planning period is to draw up a set of detailed plans for the sharing and staffing of existing laboratory facilities for research in archaeological, ethnographic, and art historical materials. Eventually, such shared facilities should enable both coordinated research projects to be carried out - research projects undertaken by a group of Center and visiting scholars – as well as the smaller projects of individual scholars.

During its first three years of operation, CMRAE will organize a series of professional seminars the purpose of which will be to explore the most pressing problems in the general domain of materials research in anthropology, archaeology, art history and related disciplines and to identify the creative routes by which the Center, as a coordinated unit of laboratories, can address and resolve those issues.

The Center's education program is based on a four-year cycle of inter-institutional courses at the graduate level covering the primary groups of materials encountered in archaeology – namely ceramics, stone, metal, and floral and faunal materials – and the issues that revolve around the documentation and interpretation of their cultural use. CMRAE is not a degree-granting institution, however. Students participating in its courses receive credit at their home institutions.

Thus far, the laboratory classes have been held at the teaching facilities available to individual faculty members at their own institutions. The NEH education grant, awarded to support the Center's education program, will permit the establishment of a central Teaching Laboratory as the primary facility for such instruction. The Teaching Laboratory will accommodate all students in the program and will be used by all faculty teaching laboratory courses.

Book reviews

IRON AND STEEL W K V Gale (Historic Industrial Scenes Series) Moorland Publishing Co., Buxton. 1977, pp 112. illus. 133 £4.95.

Keith Gale is well known to the Society as one of its past Chairmen and is widely recognised as a leading authority on the history of the iron industry and particularly of that of his beloved Black Country. Furthermore, for many years he has built up a very large and probably unique collection of illustrations of the industry through the ages. He is therefore exceptionally well placed to write such a book as the one under review.

An initial ten pages are devoted to a short history of iron and steel. It is fiendishly difficult to write a comprehensive account of a technical subject in such a way that it can both be understood by the layman and be valuable to the expert. The author obviously recognises the problem and has made a valiant attempt to solve it but it is easy to be critical. For example, it may be doubted whether the layman will appreciate the differences between dry puddling and pig boiling in producing malleable iron and even the expert has to think carefully from the account given.

The really valuable part of the book is the illustrations with their accompanying notes. These are generally of high quality and give the work some of the characteristics of a coffee table volume, though sharply distinguished from that class by the modest price. The first 29 photographs are of blast furnaces from primitive Indian examples up to those of today. The next 27 record the fortunes of the wrought iron industry. Bulk steelmaking is covered by 23 and rolling by 25. Casting and forging are allotted 25 and a final section of 5 illustrations entitled 'Iron and Steel Products' turns out to be examples of castings.

One omission is that of the activities connected with cutlery and edge tools, typically associated with Sheffield, a field which another past chairman has made his own. Cementation is noted in the index but cannot be found where indicated. Some of the sections include pictures of modern equipment, but not all do, and those left solely with illustrations of old fashioned practice might feel disgruntled at the implication that no modernisation has taken place. The bulk of the photographs relate to equipment of the 19th and early 20th centuries and it is in this field that the publication is of such value.

The detailed notes to the photographs are full of interesting information. It is fascinating to learn that the smith heating in a stock hearth a large piece of wrought iron ready for forging was able to judge the temperature of the unseen iron by prodding it with a rod and feeling how soft it was. This was indeed a specialised hot hardness test!

There is no doubt that the book will be a source of pleasant reference for many years to come.

M M Hallett

THE HISTORY OF THE DOWLAIS IRON WORKS, 1759-1970 by John A Owen, The Starling Press, 1977, £3.50.

This volume is dedicated 'to the Workmen and Managers of the Dowlais Works, past, present and future'; this seems particularly appropriate since there have been three separate phases in the history of the works.

Dowlais had the reputation of being 'the greatest ironworks in the world' in the 1840s, with eighteen blast furnaces, each producing 100 tons of pig iron every week; this was puddled and finish-rolled into railway bars and bar iron to total some 75,000 tons per annum or more. The works at this time occupied over 40 acres, almost one third covered by buildings; 7300 men, women and children were employed, including the miners who produced some 80,000 tons of ironstone and 140,000 tons of coal per annum. This was the logical development from the small beginnings of 1759, although it should be noted that the first blast furnace was coke fired, at a time when the majority of pig iron was still produced in small charcoal fired furnaces. The main growth was intimately connected with the business talent of the Guest family and in particular with Sir Josiah Guest, who was in control from 1814 to 1852.

His widow, Lady Charlotte, took up the burden herself for a few years and eventually saw the company change in character from an iron works to a steel works. She is, however, mainly remembered for her care for the workforce, the provision of schools and scholarships, a library, the benefit societies, the Memorial Hall and a medical welfare scheme. In spite of her care, however, the sanitary conditions in South Wales remained essentially primitive, to say the least of it.

The growth of the steel works, following the development of the Bessemer process, was largely the work of William Menelaus, who became General Manager in 1856; at his death in 1882, there were seventeen blast furnaces, but with double the output of 40 years earlier, a total of 186,000 tons of pig iron being made, from which 20,000 tons of open hearth steel, 104,000 tons of Bessemer steel and 52,000 tons of puddled iron was produced. The decline of the South Wales works in the early years of the twentieth century did not, however, pass Dowlais by and, despite reorganisation, Dowlais Works closed as an iron and steel producer in 1930, the mills being closed in 1936. Only the Foundry survived, eventually to be extended to produce ingot moulds and general castings, which it still does.

All this story is told here in detail – an amazing amount of detail, in fact, covering such items as the raising of the Volunteer Force during the Napoleonic Wars and the much later Dowlais Rifle Corps, depressions and riots, the first strike, the first school, the first steam locomotive, the cholera epidemic of 1849 and the gruesome details of the insanitary conditions at the time, the canal and railway transport, production details throughout the whole period and sketches of all the main characters involved. It is, indeed, a very thorough and most comprehensive history of an undertaking which spans the whole period of the Industrial Revolution.

It is accompanied by well over a hundred illustrations; as the publisher points out, several of these have been, of necessity, produced from old and faded originals and it has to be admitted that this does reduce their impact, but the comprehensive nature of this collection is again surprising.

The volume is obviously the result of loving and painstaking research; one could perhaps wish for a little more polish in the presentation but this is a carping criticism of a work which will be a standard reference for the historian – economic, technolgical or social – who has an interest in this phenomenally successful nineteenth century undertaking.

K C Barraclough

1977 INDEX TO THE CATALOGUE OF BRITISH MUSEUM ADDITIONAL MANUSCRIPTS NUMBERS 6676 TO 6686.

Miriam Wood, 2 Vols, foolscap, 307 pp. Derbyshire County Council, £3.00.

Adam Wolley in 1827 bequeathed some 53 volumes of bound papers on Derbyshire to the British Museum, of which 6676 to 6686 are almost entirely concerned with lead mining and related material, which Wolley had collected both professionally as an attorney, and as an antiquarian. Though two important attempts have previously been made to catalogue them, they have, for practical purposes been only partially usable, partly due to their bulk and complexity, partly due to their deposition away from the County of origin.

A few years ago the Derbyshire County Library were persuaded to buy a microfilm of the papers, whilst Derby Library bought a microfilm of the eleven lead mining volumes, thus once again allowing local users access to this most important collection. They have now taken this a logical step further, so that Mrs Wood is well on the way to completing an entire index, with this, for the most used group of volumes at last available.

The first of the three volumes (124 pages) has a descriptive list of the documents, reasonably brief for each entry; but with sufficient detail to allow use in many cases without referring to the originals or microfilms. Most of the documents documents relate to legal disputes or agreements of the 17th and 18th centuries, with a few later, and with a fair sprinkling of antiquarian material of an earlier date. The second and and third volumes are devoted to an index of persons, places, and subjects, and are a necessary adjunct to the first.

As anyone who used the Wolley Collection before this index was compiled will attest, Mrs Wood's task was enormous. The scholarly quality of these first three volumes to be published more than justifies her effort, and the Library's enterprise. Pleasing to see too that the County Library has resisted the temptation to use more expensive printing and binding methods, which could so easily have tripled the cost: those who buy books to store on shelves may be a little disappointed in the typography, and the continued use of foolscap is a little inconvenient today, but those who buy them to use will be delighted. We look forward to the index of the other volumes.

The catalogue is available from the Derbyshire County Library, County Offices, Matlock, Derbyshire.

Lynn Willies.

Abstracts

GENERAL

B G Scott: Remanent metal structures in corrosion products from an early medieval iron knife. Ir. Archaeol. Res. Forum, *1976, 61–4, pl, figs, refs.*

A particularly informative occurrence of remanent and fossil structures was observed in a 14th-century knife formed of two plates of carburised iron welded on to an iron core. Etching of the section revealed the fossil structures (corrosion replacement of the original structure) and remanent structure (eg. flecks of pearlite or ferrite identifiable in a corrosion matrix). Information can thus be obtained from apparently amorphous lumps of rust.
CL(BAA)

K Roesch and H M Kuhn: Artificial production of bloomery iron and its working. *Arch. Eisenhutt. 1976,* 47 *(1), 5–8 (In German).*

Simulated iron-making experiments done by heating charcoal and iron ores in a mixture of CO and H_2 at $1070^{\circ}C$. The iron obtained was carburized by heating in a crucible with charcoal. High phosphorus ores (2.4% P_2O_5) caused difficulties, but these are related to the reduction technique used and would not occur with techniques giving large slag volumes.
RFT

Cyril Stanley Smith: Historical notes on the coloring of metals. In Book: Recent Advances in Science and Technology of Materials, Vol. 3 (Cairo Solid State Conf. II 1973). *Plenum Press, New York and London, pp 157–167, 1974. 15 refs.*

Decorative surfaces produced on metals in the Middle East, Egypt, South America and the Far East reveal a rich knowledge of chemical and metallurgical reactions. In addition to mechanical surface reatments, chemical etching and cementation-diffusion reactions were used decoratively in the 3rd millenium BC. Metallographic studies of many objects are described, and the early literature containing metal-coloring recipes is discussed, including its relation to alchemy.
EWF

Jerzy Piaskowski: How alloy steel was invented. *Wiad. Hutn, March 1976* 32 *(3), 103–107. In Polish. 19 refs.*

The manufacture of wootz (Indian steel), the damascene process, and the researches of Stodart, Faraday and others are discussed.
MG

Michal Gradowski: Glossary of Polish terms for goldsmith's articles. *Biblioteka Muzealnictwa·i Ochrony Zabytkow. 1976,* 44B, *1–55. In Polish, Mimeographed.*

This is a unique collection of terms used by present and past craftsmen intended to help in understanding old texts.
HJ

M J Cole: Gold in Jewelry. *Metals Australia. Feb. 1976,* 8 *(1), 22–23.*

The use of gold in jewelry is traced from early civilizations to the present. The carat-system of gold alloy identifications is described and the melting ranges, hardnesses, minimum elongations, and annealing temperatures are tabulated. The ternary alloy stem gold-silver-copper is discussed and a ternary diagram is presented which details the colors of the various alloy systems.
MG

BRITISH ISLES

B G Scott: The occurrence of platinum as a trace element in Irish gold; comments on Hartmann's gold analyses. *Jr Archaeol Res Forum, 1976, 3(2), 21–4 refs.*

Attention is focused on the most controversial of Hartmann's groupings, PC, which he suggested had a Rhenish source. However, a 19th-century account of the identification of platinum found associated with alluvial gold in Wicklow appears trustworthy. Further implications of this finding for Hartmann's results are outlined; hopes of a completely fresh analytical programme are, however, slim.
CL(BAA)

K S Painter: The Mildenhall treasure; Roman silver from East Anglia. *London, British Museum Publications, 1977, 79 pp, pls, figs, refs, tables. Price £1.50 (paper).*

Illustrated catalogue of the treasure, with accompanying discussion of its date, origins and ownership, and results of examination of the Great Dish by metallography, scanning electron microscopy, X-ray fluorescence analysis and atomic absorption analysis. Many new photographs are included and comparisons with the Traprain and other treasures drawn; seven of the Mildenhall pieces depict subjects matched on the contorniates (pagan propaganda medals) of about AD 360, a time of increasing insecurity in Britain.
(BAA)

Rosamond Hanworth and D J Tomalin: Brooklands, Weybridge: the excavaton of an Iron Age and medieval site, 1964–5 and 1970–71. *Res Vol Surrey Archaeol Soc, 4, 1977, 88pp, pls, figs, tables, refs. TQ 068632.*

Trial excavations were followed by stripping of 3000 sq m five years later. Occupation on what was probably part of a larger Iron Age settlement ran from 6th century BC to the Roman conquest. Iron forging and smelting were carried on and there were pits of various types and a penannular house gully. The well-known Weybridge bronze bucket came from the river at this point. Saxon material of 8th century was not associated directly with any structure. A small medieval estate then followed: five or six buildings within a ditch and palisade are tentatively dated 1150/75 to early 14th century, with documentary evidence cited for a Broc/Brok/Brooke family. Specialist reports on pottery, iron working operations, building materials, medieval ironwork and bronzes, flints, querns and bones are provided.
CL(BAA)

Owen Bedwin: The excavation of Ardingly fulling mill and forge. *Post-Medieval Archaeol, 1976,* 10, *34-64, pls, figs, refs. TQ 334289.*

The remains of a 16th and 17th century forge and an 18th century fulling mill were excavated. The centre of industrial activity lay between two parallel water channels 9 m apart. The forge, of which little survived apart from the anvil base and some wooden foundations, had used wheels in both channels, driving respectively the power hammer and the

bellows for the hearths. Fulling, carried out in a simple T-shaped shed, required one wheel only. The site went out of use c.1750. Author (abridged).

CL(BAA)

B G Scott: Metallographic study of some early iron tools and weapons from Ireland. *Proc. Roy. Irish Acad. 1977,* **77C** *(12) 301-317.*

Metallographic examination of a group of 9 early iron tools and weapons of diverse origins reveals a range of production techniques. Several of the artifacts have had specially selected edges welded on, and one of the spearheads (badly damaged by corrosion) has a pattern-welded blade. Deliberate carburisation to produce both local steeled areas and relatively homogenous steel, as well as heat-treatment, provides evidence of an early appreciation of the potential of the physical properties of iron and steel and of the techniques needed to manipulate these properties. After a sufficiently large number of similar examinations have been carried out, technological information should be a useful tool in the construction of typologies of iron artifacts which at present are difficult to classify by shape alone.

Author

John Malden: The Walker iron foundry, York, c 1852-1923. *York Hist, 1976,* **1**, *37-52, pls, refs.*

Discusses York's foremost 19th-century ironworks and provides a list of its products, including work for Kew Gardens and the British Museum.

CL(BAA)

M U Jones, J P C Kent, J Musty, L Biek: 'Celtic coin moulds from Old Sleaford, Lincolnshire'. *Antiquaries Journal, 1976,* **106**, *238–241.*

Brief report of the finds from the Celtic Mint site at Old Sleaford, which consisted of a few pieces of crucible and slag and 3000 fragments of moulds for casting coin blanks. One coin pellet was found in situ in a mould and reported to contain silver and copper in the approximate ratio 2:1. The method of use of the moulds and parallels for the find are discussed.

WAO

Hugh Toller: Roman lead coffins and ossuaria in Britain. *Brit Archaeol Rep, 1977, 38, 87 pp, figs, tables, refs. Price £1.90 (paper).*

Lists, maps and discusses 243 lead coffins, 27 ossuaria and 17 lead tanks and other vessels. Analysis of decorative and non-decorative features is made and technological details provided.

CL(BAA)

K S Painter: The Water Newton Early Christian silver. *London, British Museum Publications, 1977, 48 pp, pls, figs, refs. Price £1.50 (paper).*

Detailed catalogue of the recently-discovered hoard from **Durobrivae** in its 'as found' condition, with discussion of the possible circumstances of its deposition. Not later than 4th century in date, which makes it nearly two centuries earlier than other known Christian treasures, the hoard contains plaques of pagan type but with **Chi-Rho** symbols.

CL(BAA)

Michael Owen: Antique cast iron. *Poole, Blandford Press, 1977 x + 127 pp, pls, figs. index. Price £3.75.*

Plots the rise and decline of domestic cast iron as used for balconies and railings, door furniture, scrapers and door porters, and fireplaces. Many illustrations are reproduced from catalogues of firms such as Kenrick, Carron and Dale, and the entry to and disappearance from the dated catalogues of specific items in the period 1840–1926 noted.

CL(BAA)

Tony Gregory: A hoard of late Roman metalwork from Weeting, Norfolk. *Norfolk Archaeol, 1976, 36, 265–72, figs.*

The hoard of kitchen ware consists of a large bronze cauldron seven smaller bronze vessels, and various iron objects including a cauldron-hanger. One vessel is a **bassin à bord godronne** and the hoard is assigned a date in 4th or 5th century.

Author (adapted) CL(BAA)

M Herity and G Eogan: Ireland in Prehistory. *London – Henley – Boston 1977.*

Iron smelting of the La Tène period traced at Rath na Seanaid, Tara, and Freestone Hill. The earliest iron artifacts are Celtic swords of the 2nd century BC. see pp 223, 234–236.

CPSA

A Thompson and E Holland: Excavation of an Iron Age site at Dellfield, Berkhamsted. *Hertford Arch. 1977, 7, 137–148.*

Yielded 4 shaft furnaces with slag tapping pits; they were 30 cm diameter and the tallest was 60 cm high. Tap slag was high in iron low in S and had 0.23% P and 0.52% Mn. They probably date to the first century AD.

RFT

D M Metcalf and D R Walker: Tin as a minor constituent in two sceattas from the Shakenoak excavations. *Numismatic Chronicle, 1976, 16, 7th series, pp 228–229.*

The occurrence of tin in the seatta series of Anglo-Saxon coins is discussed in the light of the meager evidence so far available and results of x-ray fluorescence analysis are presented for two newly excavated coins. One contained Ag 7.0%, Sn 8.5%, Pb 2.25%, and the remainder Cu.

WAO

Anon: When cannon were made in cast iron. *International Modern Foundry. 1977(4), p.6.*

Surveys cannon founding between 1543 and 1852. Mentions the introduction of high strength cast malleable iron cannon balls by Prince Rupert.

P Holdsworth: 'Saxon Southampton; a new review'. *Medieval Archaeology, 1976, 20, 26–61.*

This review contains a very short section on metalworking. There is no evidence for working precious metals, but some lead waste has been found. However the main evidence is for bronze (moulds, crucibles and (?) unfinished objects) and iron (furnace and hearth, ore and badly oxidised iron objects).

WAO

N Mutton: The Marked Bar Association: Price Regulation in the Black Country Wrought-Iron Trade. *West Midland Studies (The Polytechnic, Wolverhampton), 1976 vol 9, p.2.*

'Marked bars' was a term applied to a number of items made by a small number of specialist producers. Its status depended entirely on the reputation of those producers, without any supporting technical specifications. The Association started in 1871 and the last meeting was in 1934. It worked closely with the older and larger South Staffordshire Ironmasters' Association. The practice in controlling prices through periods of boom and depression is described.

MMH

J G Worpell: The Iron and Coal Trades of the South Staffordshire Area Covering the Period 1843–1853. *West Midland Studies (The Polytechnic, Wolverhampton) 1976, 9, 34.*

The paper consists largely of a series of reports taken from issues of the Wolverhampton Chronicle. During this period there were a number of both large and small fluctuations in the state of trade. Many consequent meetings of the iron-masters took place and in times of depression the selling prices of bar iron would be lowered to stimulate demand. In order to balance the loss in revenue, it was quite normal to lower wages which in turn often brought about strikes. Parallel struggles went on in coal mining and fluctuations in the price of coal were an important factor in influencing the price of iron. The lowest price for first class bar recorded in the period studied was £5 per ton and the highest was £10 per ton.

MMH

EUROPE

J P Mohen: What can one learn from the radiography of protohistoric objects of bronze? *Bull. de la Société Préhistorique Francaise, 1973,* **70** *(7), 205–210. (In French)*

Shows how radiography can reveal hitherto unexpected detail such as the complex nature of the joining of hilts to sword blades and hollow bows in fibulae. The latter had a clay core held in place by a 'prints' which left two holes in the casting. The core was removed through these holes and the holes were filled with a rivet.

RFT

J Briard and J P Mohen: The tumulus of the forest of Carnoet at Quimperlé (Finistére). *Antiquités Nationales, 1974, 6, 46–60. (In French).*

Yielded a number of EBA dagger blades, bracelets, spearbutts etc of bronze and arsenical copper. The authors have carried out a detailed metallurgical examination on the dagger blades and their rivets which were both of arsenical copper in the range 5–7% As. The surface of the 7% As blade had been enriched in As to 29%. The 5% As rivet was mainly single phase with slight grain – boundary enrichment in As. The structure of the blade was duplex. It is believed that the arsenical coppers were made by mixing minerals and that the surface enrichment of the blade was by a cementation process in an arsenical mineral after working. This possibility was tested in the laboratory.

Comparisons are made with other local, Iberian and Wessex material.

RFT

J P Mohen: Baked clay moulds used by prehistoric bronze smiths. *Antiquités Nationales, 1973, 5, 33–44 (In French).*

Discusses clay moulds, which are in the National Museum at St Germain – en – Laye, for swords, spearheads, socketed axes, bracelets, pins etc from French and Swiss sites dated from the MBA to the LBA. Believes that a metallographic examination of the bronze artifacts should allow one to decide whether the artifact has been made in a mould of clay, stone or bronze.

The clay moulds examined were made from carefully prepared clay in two-parts; the inside very refractory and the outer part tempered with vegetable material. They represent the response to a different need, ie. a 'one-off' requirement compared to the mass production implied by the stone and bronze moulds.

RFT

U Zwicker, E Grembler and H Rollig: Investigations on copper slags from Cyprus (2nd Report) *Rep. Dir. Antiqs. Cyprus, 1977, pp 309–312.*

The investigation of slags from Enkomi (1200 BC) show that this site has been used from the beginning of copper production with small furnaces, which produced no tap slag. In all the slag-pieces investigated metallic copper was present. Sulfide inclusions are scarce. Contrary to the preliminary report, in several places at Enkomi slag-pieces without a measurable content of molybdenum were detected. Also, in Enkomi, copper has been produced which did not contain molybdenum. The molybdenum content varies to a great extent so that, in the course of time, ore without a detectable content of molybdenum may have been smelted at Enkomi. Slag containing no sulphide and slag containing a small amount of sulphide was produced. Also, in copper slags from Hala Sultan Tekke and from Kalopsidha sulphide was not observed.

In all other places (660 BC – 350 AD), from which copper slag was investigated, sulfidic ores were smelted. No metallic cooper was included in most of the slag-pieces from these sites. Therefore one must assume, that either the oxidation of the ore was incomplete or that only matte was the product of the smelting process and that metallic copper production took place elsewhere. A lack of charcoal may have been the reason for such matte production. Further investigations are necessary to find out more details on the development of the copper smelting industry in Cyprus.

Author

Anon: Napoleon authorized the building of the first Hoesch blast furnace. *(In German). Wirk und Wir (House magazine of Hoesch Werke Ab.) 1974 (12), 323–5.*

Built by Eberhard Hoesch in 1806 at Vossenack; the oldest existing German charcoal furnace which in its time produced 270 tons per year.

S I Tatarinov: A Bronze Age mining- and metallurgical centre in the Donbas. *Sov. Ark. 1977 (4), 192–207 (In Russian).*

The problem of such a centre in the Donetz basin is more than a century old. Specialists have been interested, in particular, in the copper mines at Bakhmout as a source of the metal. The author of the present paper, in collaboration with geologists, has been investigating settlements near mines in various villages of the Donetz region. They have found remains of ores and copper slag. In one village two smelting furnaces were found together with slag and ore, tools, crucibles, part of a three-part clay mould for a spearhead with butt, and some picks. The spectrographic analysis of the ore, the slag and the metal have shown that copper with a slight arsenic content was produced. The local ores show traces of Hg, Sb and As and it is suggested that they were used with added tin to make bronze. The dating of the pottery is the end of the 2nd millennium BC (LBA) but it is likely that the mines have been exploited from the Eneolithic to the beginning of the Scythian period. (800-600 BC).

ECJT

S V Kouzminykh: The chemical composition of metal from the Urnfield at Sokolovski. *Sov. Ark. 1977 (4), 279–283 (In Russian).*

Includes socketed and shafthole axes and knives. Of five copper-base objects analysed all but one are of arsenical copper (0.1–2.0% As). The exception is a bronze saw-knife with 4.8% Sn and 2% As. The iron contents are in the range 0.045–1.2%).

ECJT

Torsten Berg and D F Nettell: Iron marks on turret clocks. *Antiq. Horology, Winter 1976, 78–81.*

Swedish ironmaster's marks indicate that some of the iron work of these clocks is Swedish wrought iron dated to the 18th century.

RFT

Christian Dubois: Notes on the keels of Roman Ships. *Rev. Archéol Narbonnaise, 1976, 9, 155–75, figs. refs.*

A re-appraisal of the evidence for Roman keels and adjacent timbers. Three keel types are postulated: those of 2nd and 1st century BC with garboards of asymmetrical section (? fashioned from the solid), double planking, and lead sheathing; undated and special keels; keels of 3rd and 4th century AD with plank-like garboards forced into position, no hull protection, copper and iron rivets, and efficient keel scarfs. A distinction is drawn between frames fastened to a keel as active moulds, and fastenings merely to consolidate keel/frame assembly. The evidence for intermediate shell/skeleton construction in 3rd and 4th centuries AD is believed to be convincing. S McG CL(BAA)

Michell Vieau and Monique Bigoteau: Study of collections from the Bronze Age in the Natural History Museum of Nantes, du Musée du Chateau de Noirmoutier, du Musée de Chateaubriant Etudes préhist protohist, Pays de la Loire, 1974–6, 4, *Assoc d'Etudes Prehist Protohist des Pays de la Loire, 1976, 138 pp typescript, figs. refs.*

Catalogue of mainly unpublished Bronze Age material from the collections of the three museums named, including data on spectrographic analyses, distribution maps, etc. The second author contributes a section on the bronzes from the Ch. Mercier collection at Nantes. CL(BAA)

Jacques Briard, Y Onnée and Y–Y Veillard: The Bronze Age in the Brittany Museum. *Rennes, Musee de Bretagne, 1977, 170 pp, pls, figs, refs, indexes. Paperback.*

The introduction to this illustrated catalogue describes the origin of the Museum's collections and outlines the chronological sequence of Breton prehistory from the Palaeolithic to the Bronze Age. CL(BAA)

V G Kotovitch: Questions on early copper metallurgy and its connection with the appearance of iron in the Caucasus. *Sov. Ark. 1977 (3), 69–78 (In Russian).*

Based on the idea that amongst several diverse and complex reactions occurring when one smelts chalcopyrite is the formation of metallic iron. Until more recent times the possibility of limiting or regulating the factors influencing these reactions seemed nonexistent so that smelting of this sort was inevitably accompanied by the formation of ferrous phases containing 76-90% of metallic iron. The study of archaeological data in our possession shows that the first attempts to smelt chalcopyrite had already taken place in Asia Minor at the start of copper metallurgy and in the Caucasus no later than the 3rd millennium BC. This is why it is possible to record the appearance on sites dated to 3rd – 2nd mill. BC of isolated objects of iron, at first ornaments and, later in the period, arms and tools. ECJT

C Dunant, H Durant and F Schweizer: A Greek *patera* with a leonine handle. *Genava, 1976, NS 24, 307–322 (In French).*

Prior to restoration 3 parts of the object were analysed and found to contain (%):–

	Sn	Pb	Sb
bowl	8.5	3.5	< 0.1
lion handle	2–3.5	7–19	< 0.1
ring handle	2	7–9.5	< 0.1

The thickness of the bowl was 0.2–1.0 mm with intentional thickening at the rim. The metal had been annealed several times during working and had been finally cold worked. The handles had been attached with soft (Pb-Sn) solder. A sand sample from the core of the lion handle gave a thermoluminescent date of mean age 300 BC proving that it is not a fake. RFT

G Cordier and J–P Mohen: A Bronze Age metal hilted dagger from the Museum of the Vendome. *Bull. Soc. Arch. Vendomois, 1972, 19–24 (In French).*

Bronze hilted of MBA. Analyses of the hilt, rivets and blade gave 14.2–14.7% Sn together with Ag, As, Sb and Ni, but only a trace of Pb. No microstructural examination done. RFT

S Albert and P Schröter: New find of the Michelsberg culture in the Tubingen district. *Archaeologisches Korrespondenzblatt, 1975, 5, (1) 15–22.*

A blue spot on a jaw bone from a pit of the Michelsberg culture (Germany) seemed to indicate the presence of copper. A copper implement so early in the neolithic age would have been noteworthy. Chemical analysis however showed the absence of copper, but iron was detected: thus the blue is most probably caused by vivianite. RCAR

J Francais and J Liszak-Hours: Analysis of Bronze Age arms and implements from the Paris region. *Annales du Laboratoire de recherche de Musées de France, 1976, pp 46-57 (In French). Bibliog., 5 photos, appendix.*

Within the framework of the research program on ancient metallurgy pursued for several years at the Research Laboratory of the Museums of France, 68 objects from the Museum of National Antiquities were analysed by X-ray spectrometry.

The appendix contains a typological list of the objects and the table of analytical results. These results are discussed and data compared with chronologies established on typological criteria, confirming them or rectifying errors. LW(Trans. IVB)

Ryszard Kiersnowski: Barkwald-one more 15th century forgers' mint. *Wiadomosci Numizamatyczne, 1975, 19 (1) 1–13 (In Polish. Eng. summary).*

Forgers in Poland and the neighbouring countries were particularly active in the 15th century. A new mint is added to the presently known list according to information from Annales Glogoviensis. Details of its work and activity are given. HJ

Ryszard Kiersnowski: Coin imitations and forgeries in the Middle Ages *Wiadomosci Numizmatyczne, 1973, 11, 81-90. (In English).*

Present knowledge of the procedures and the differences between imitation and forgeries are discussed. HJ

J D Muhly, T S Wheeler, R Maddin: The Cape Gelidonya Shipwreck and the Bronze Age metals trade in the eastern Mediterranean. *Journ. Field Arch. 1977, 4, 353-361.*

Examines ox-hide, plano-convex and oblong (slab) ingots from the shipwreck and compares them with ingots from Gournia, Enkomi and Mathiati. Spectrographic AA analyses are given together with metallography. The oblong ingots from the shipwreck (previously reported by Bass to be bronze) were found to be much lower in tin (0.1–2.0%). They conclude that recent studies of ox-hide ingots in the Mediterranean indicate no general provenance but that they are evidence of an extensive trade in metal by entrepreneurs. RFT

Jerzy Pininski: Problems of counterfeit currency in the 15th century in the light of Polish and Czechoslovakian finds. *Wiadomosci Numizmatyczne, 1973,* **11**, *91-105. In English.*

General considerations are followed by technical details.

HJ

Zofia Stos-Fertner: The application of radiosotope X-ray fluorescence analysis for the determination of heavy metal impurities in Kufic silver coins. *Wiadomosci Numizmatyczne, 1975,* **19** *(4), 207-224. (In Polish. English summary).*

Different amounts of Cu, Pb, Hg and Bi were found as impurities in the high-silver-content coins. No surface enrichment of silver was observed. There is a detailed discussion of analytical results and on the possibility of classification of coins according to the content of impurities. Details of the method and some tables are included.

HJ

Stanislaw Suchodolski: The organization of minting in 11th and 12th century Poland. *Wiadomosci Numizmatyczne, 1973,* **11**, *63–80. (In English).*

Different aspects of coin production, the kinds of coins produced, the organization of production and other technical details are considered.

HJ

Otto Werner: West African manillas from German metal ore smelters. Working up of copper scrap in the 15th and 16th centuries. *Erzmetall. 1976,* **29** *(10). 447-53. In German.*

Cobalt-containing wastes from Harz Mountain smelters resemble in composition the manillas in circulation for many centuries in West Africa. Indications are that in the 15th and 16th centuries, similar wastes from North German smelters were converted into such materials and exported to West Africa, where they were preserved intact up until 1948. Such wastes and manillas were also used, both in Europe and Africa, as additives in the melting of brass and bronze. The chemical composition of a number of such brass and bronze specimens is given.

Jan Reyman: Remarks on some aspects of the determination of silver content in coins by X-ray fluorescence *Wiadomosci Numizmatyczne, 1974,* **18**, *(4), 226-229. (I n Polish. English Summary).*

This is a comment on the article by Stos and Tworkowski who noted that the silver content of coins was higher than in the mint ordinance, which Reyman considers improbable; he believes that the analyses are accurate but that information on the mint ordinance will have to be checked.

HJ

Josef Riederer: Metallurgical examination of east gothic costume ornaments. *In V. Bierbrauer: Die ostgotischen Grabund Schatzfunde in Italien, pp 231-238 (1975) (In German).*

17 Fibulae from the Gothic period in Italy were analyzed. It was found that silver alloys with high amounts of copper and zinc were used. Silver varies between 18 and 88. Copper between 8 and 67, and zinc between 1 and 15 per cent. Obviously the fibulae were cast from silver, copper and brass coins which the silversmith received from his customers.

JR(AA)

Zofia Stos and Tadeusz Florkowski: Determination of silver content in coins by non-destructive radioisotope X-ray fluorescence analysis. *Wiadomosci Numizmatyczne, 1974,* **18** *(2), 85-97. (In Polish. English summary).*

Details of the method and results of analyses are described for some 16/17 century Polish coins. The condition of the coins was considered to be very good, which led to conclusions concerning the original composition of the alloys. The observed surface enrichment is attributed to blanching.

HJ

A R Williams: Roman Arms and Armour: a Technical Note. *Journal of Archaeological Science, 1977,* **4**, *77-87.*

Metallographic examination of one Roman gladius and one piece of lorica segmentata (Ristissen, Germany, 2nd century AD); both specimens made of pearlitic steel with varying carbon content (under 0.7%), and not hardened.

CPSA

A R Williams: Methods of manufacture of swords in medieval Europe: illustrated by the metallography of some examples. *Gladius (Madrid), 1977,* **13**, *75-101.*

Eight medieval swords (12-15th centuries AD) from several museum collections show a good deal of case-carburized blades (heat treatment). Others are welded together by piling iron and steel parts.

CPSA

R Pleiner: Extensive iron production centres in Germany; *In: Symposium Ausland der Latene-Zivilisation und Anfange der germanischen Besiedlung in mittleren Donaugebiet (1972). Bratislava 1977, 297-305.*

In contrast to scattered iron smelting industry among the Teutonic tribes there appear, mainly in the Late Roman period, bloomery centres with large-scale production, especially in NW Germany, West Jutland, Silesia, Little Poland, and in the Carpathian Basin. The technology was based on slag-pit furnaces. In the above centres archaeologists have discovered vast fields of remains with hundreds of units.

CPSA

Histoire du Fer. *Guide illustré de Musée de Fer, Jarville pres de Nancy. 2nd edition. Jarville 1977.*

Among numerous illustrations the Celtic iron cuirasse from Dormans/Marne and the Gallo-Roman stele from Dieulouard (Meurthe-et-Moselle) depicting three blacksmiths working at an anvil deserves special attention.

CPSA

V Souchopova: Slag tapping iron smelting furnaces of the 11th century (In Czech.) *Olomucany Forstabteilung Nr. 99. In: Z dejin hutnictvi 3 – Rozpravy Narodniho technickeho muzea v Praza 1976,* **68**, *7–11.*

Shape of slag in a West Moravian iron making centre indicates the use of tapping furnaces. Tuyere panels. Limonite ores with elevated calcium content.

CPSA

R Schindler: Traces of iron smelting in Roman villas on the Moselle. *Trier Zeitschrift 1976,* **39**, *45–49.*

After the collapse of the Roman economy and of the distribution system in the area of the Moselle river, several Roman villas started their own iron production about the end of the 3rd century AD. Stone-walled furnaces at Hetzhof-Bengel, Serrig, and Hochscheid. Brick-shaped tuyeres and a conical slag block.

CPSA

A M Rosenqvist: Metallographical examination and hardness tests of rings and bangles. *Universitetets Oldsaksamling Arbok 1975/1976, 117-122.*

Early medieval ornamented iron rings inlaid with brass or gunmetal. The core is of mild ferritic-pearlitic steel (Widmanstätten texture).

CPSA

J Plaskowski: Classification of the structures of slag inclusions in early objects made of bloomery iron. *Archaeologia Polona 1976,* **17,** *139–149.*

In the author's opinion slag inclusions may be related to iron from different geographical regions even by macroscopic estimation. In his second attempt he divides the inclusions in objects from Poland into four groups; inclusions from foreign countries are divided into 8 other groups. The division is based on visual appearance without considering the true mineralogical and chemical composition. CPSA

T J Horbacz: A sword with images of Mars and of Victory from the collection of the State Archaeological Museum in Warsaw. *Wiadomosci Archeologiczne 1976,* **41,** *(3), 281-291.*

A pattern-welded Roman sword with copper inlays from an unknown site in Poland (one of four examples known up to the present day). The author suggests that it dates from about 200 AD (after the Marcomannian wars); possibly a Roman gift to personalities of high rank among the barbarians. CPSA

J Gomori: Ancient Bloomeries in Sopron. *Szoproni Szemle 1976,* **30** *(3), 239-255. (In Hungarian).*

At Sopron, West Hungary, bloomeries were excavated equipped with two dug-in furnaces dating from the 10th century AD. Another site is at Nemesker, where a smelter's and blacksmith's settlement was discovered, having preceded the Hungarian invasion of about 900 AD. The site consist of 40 slag heaps, 3 shaft furnaces, and a reheating hearth, tuyere, tongs, etc. CPSA

V E Artilakva: Iron working crafts of ancient Georgia. *Tbilisi 1976. 263 p. incl. 93 plates, 2 charts. (In Russian)*

The book brings before the reader various archaeological, iconographical and historical data relating to the blacksmith's work in Georgia. Excepting some of the 8th-7th centuries BC finds (Citachevi) the main topic deals with the craft of the early and high medieval periods. It should be stressed that the work aims to date numerous but not stratified specimens of blacksmith's tools and artifacts in museum collections.The contents may be characterized as follows: I Blacksmith's work and tasks of research. Historiography and sources. II Centres of iron making and working, III Blacksmith's tools. IV Woodworking tools. V Domestic utensils. VI Farmer's implements. VII Structural iron. VIII Arrow- and Lance-heads, swords and daggers. IX Technology of the blacksmith's work. X Social position of black- and locksmiths in Middle Ages. Biographical remarks remarks on some medieval artisans in Georgia. Conclusions – Chapters III and IX deserve special attention. Blacksmith's tools and carved stone grave plates with blacksmith's emblems from the 11th-14th centuries AD. Metallographical analyses of 57 artifacts. All-steel objects and iron-to-steel welding are relatively rare. Heat treatment in 26% of medieval cases. CPSA

M Cenek, K Bezdek, K Stransky and V Souchopova. Direct iron making process in the surroundings of Blansko. *In:– Kniznice odbornych a vedeckych spisu Vysokeho uceni technickeho v Brne, B. 61. Brno 1975, 79-89. (In Czech.).*

Results of four trial smelts in a furnace model corresponding with the slag-pit type, though the aim was to imitate a Slav bloomery furnace dating from the 11th century AD, found at Olomucany, West Moravia. The height of the test furnace varied between 370-800 cms. The best yield (31%) was from Smelt No. 4 (800 cms, ore/fuel 1:1, Indian haematite ore, high carburization of the sponge). CPSA

M Leoni: Celtic Sword blades. *Sibrium 1973-75,* **22,** *105-125. (In English).*

Four Celtic sword blades from Sforzesca (middle La Tène), and from Borgovercelli (late La Tène). Two of them were examined by specimens taken from edges; the remaining blades were examined by trepanning in central areas. Wrought iron or mild steel. Only blade No. 4 from Borgovercelli was piled from wrought iron and steel strips and marquenched. CPSA

ASIA

M M Krymina: Foundry moulds from the towns of the Golden Horde in the lower Volga. *Sov. Ark. 1977 (3), 249-267 (In Russian).*

18 stone and 2 clay moulds for jewellery were examined; they comprised 4 types:– open, two-part, joined with the aid of a dowel or pins, and special moulds with bar cores for rings and coils. The method of use of these moulds showed an advanced technique. ECJT

N Ya Merpert & R M Mountchaiv: The earliest metallurgy in Mesopotamia. *Sov. Ark. 1977 (3), 154-163 (In Russian).*

Excavations on three sites carried out in the North-west of Iran has given precise dating for early metal ages. Tell Sotto (early 6th mill. BC) gave copper beads; at Yarim Tepe I (Hassoun culture, middle of 2nd half of 6th mill. BC) were found 27 objects including copper mineral, lead and copper artifacts. In Yarim Tepe II (Halaf culture 5th mill. BC) similar objects were found. Qualitative analysis shows that most of the copper objects consist of pure copper but each site is alleged to show evidence of a different source of mineral. Frequently the iron in the objects is in the range (1–10%) which suggests that slag is responsible. Mn is present in the ores (0.1–1.0%). ECJT

W G Dever and Miriam Tadmor: A copper hoard of the MBA I. *Israel Explor. Journ. 1976,* **26,** *163–169.*

The hoard found in the Hebron hills mostly comprised bar ingots weighing from 93–285 g and having lengths from 8 to 21 cm. A dagger blade and adze completed the hoard which appeared to have belonged to an itinerant smith. RFT

R Maddin and T S Wheeler: Metallurgical study of seven bar ingots. *Israel Explor. Journ. 1976,* **26,** *171-173.*

Four analyses from the above hoard and 3 similar from Har Yeruham N–E. Negev. The results show that all seven are relatively pure cast coppers containing 0.31 – 1.7%,Fe, 1.25 – 4.8% Pb, 0.01 – 0.36% Ni, 0.015 – 0.1% Co and some Ag and S. The mean hardness was 57 HV. Such a copper is typical of local production. Most of the lead is in the form of sulphide. RFT

J D Muhly: The copper ox-hide ingots and the Bronze Age metals trade. *Iraq. 1977,* **39,** *73-82.*

A general discussion on early alloying (As and Sn) and sources; regrets that we cannot provenance copper by its composition at the present time and that the composition tells us very little about the copper trade in the Mediterranean in the LBA. More work needs to be done on both minerals and copper ingots. RFT

N Barnard: Notes on selected bronze artifacts in the National Palace Museum, The Historical Museum and Academia Sinica. In *Ancient Chinese Bronzes and southeast Asian metal and other archaeological artifacts. National Gallery of Victoria Symposium. Melbourne 1975, p 47-82.*

Discusses fabrication details in the making of Chinese bronze vessels. Includes pre-cast knobs, legs and handles. RFT

E R Eaton and H McKerrell: Near Eastern alloying and some textual evidence for the early use of arsenical copper. *World. Arch. 1976, 8 (2), 169-191.*

Emphasises the large amount of Cu-As alloys in use up and into the MBA. Suggest that tin supplies had to come from Western Europe up to the end of the third millennium; and also that **annaku** and **Oreichalkos** may refer to Cu-As alloy or arsenic-coated copper.

A J Wilson: Timna, cradle of the world's copper mining industry. *Mining Mag. 1977,* **136** *(4), 6 pp.*

Report on the latest work by B Rothenberg on the smelting side and the Bochum Mining Museum on the mining side.

RFT

M N Pogrebova: Iran and Transcaucasia in Early Iron Age. *Moskva 1977. (In Russian).*

Mrs Progrebova has analysed all available archaeological sources relating to the history of Iran and Transcaucasia in the Early Iron Age which is divided into two phases: the first of them is dated to the 13th-11th centuries BC, the second to the 10th till the 8th/7th centuries BC. During this period, east Transcaucasia was closely tied to north Iran, more tightly than the west Transcaucasian countries. The book contains some remarks on the spread of iron (sp. p 143 et seq). In the first phase, iron penetrated both to Iran and Transcaucasia slowly. Iron spear-heads later became typical of the Transcaucasian countries, and bi-metallic dagger types of Iran. The first centuries of the last millenium BC represent a period when both territories, ie. Transcaucasia and Iran, can be held responsible centres for the further spread of iron to the North and East. The author is rather critical of the dating of important find complexes by recent Georgian and Armenian scholars.

CPSA

Shiego Aoki and Kyotaro Nishikawa: Restoration of 'pressed out Buddhist images' found in the Atagoyama Tomb, Tsu City, Mie prefecture. *Science for Conservation, March 1976, (15) 36-50. (In Japanese).*

The manufacture of 'pressed out Buddhist images' was very popular in Japan throughout the 7th and 8th centuries. It is a kind of Buddhist image modeled with copper plate (0.5 mm thick) on a cast bronze prototype, and most of them are found in miniature temples called 'Zushi', indicating that they have been objects of individual worship. The objects in question were found in a stone chamber of the Atagoyama tomb in 1931.

Art historical descriptions of the images are given.

TK

S Kucera: Chinese Archaeology 1965–1974. Palaeolithic Age to the Yin period. *Moskva 1977. (In Russian).*

This excellent book bringing a survey on recent results, problems and new finds of Chinese archaeology up to about 1000 BC, contains a very important chapter on the metallury of iron in section II (pp 96-105). Considering the frequency of archaeological iron objects and the evidence of written sources it is clear that the initial phase of the use of iron in China was the period of the Late Ch'un – ch'iu and Early Chan kou (ie. roughly the 6th-5th centuries BC), when the somewhat limited but more than sporadical occurrence of iron weapons and tools is traceable among various sources. Some earlier axe blades (yu) were identified as of meteoritic metal. Now the discussion arises on new finds at Taisi (an axe blade inserted into a bronze body, Shang or Yin period, approx, 14th century BC) and simultaneously on the new interpretation of a term inscribed oin the Bay'Guy vessel (11th century BC); formerly it was read as 'inhabitants of countryside', now possibly 'iron founders'. The stratification and metal composition of the Taisi axe still involve certain problems, and the Ban Guy inscription remains but a hypothesis so that the question of iron in China in the early years of the first millennium is still open. CPSA

Maurizio Tosi: Notes on the distribution and exploitation of natural resources in ancient Oman. *Journal of Oman Studies, 1975,* **1**, *187–206.*

This survey of the agricultural, marine and mineral resources of Oman includes historical aspects of their exploitation from the Jemdat Nasr and Unman-Nar cultural periods onwards. The mineral survey is particularly illuminating as regards early copper metallurgy in the region, and includes the details of ores, mining techniques, crushing, smelting, slags, and crucible fragments. Zinc ores also occur and appear to have been worked in antiquity. MJH

Michal Gradowski: Techniques and technology in ancient goldsmithery. *Biblioteka Muzealnictwa i Ochrony Zabytkow, 1975,* **40**,*B, 1–96. In Polish, 16 tables illus. with technical details. Mimeographed.*

Shaping of vessels, embossing, using dies, casting,surface finishing, engraving, staining, joining, soldering, organization of the workshop, tools, silver and gold alloys and designing are considered.The material is collected from many possible sources, such as old treatises, recent literature, existing traditions, and information gathered personally by the author in small primitive workshops in the Near East.

HJ

M Y Ethem: On copper mining and smelting in Turkey. *Erzmetall, April 1976,* **29** *(4), 182-186 (In German).*

The distribution of copper ore and pyrites on the Turkish Black Sea Coast, the principal organizations (Etibank and Black Sea Copper Works Inc.) which mine there, and the ore dressing and extraction processes used at different sites are discussed. The copper, lead, zinc, and sulfur content, grade and estimated total tonnage of reserves and production figures are presented. ICIB

Dan Bahat: A middle Bronze Age I cemetery at Menahemiya *Atiquot. 1976, pp. 27-33.*

Three rock-cut tombs discovered recently in the Beth Shean Vally of Israel contained pottery bowls, jugs, etc. and six copper weapons; sword, dagger, javelin and 3 spearheads. Both the sword and dagger had rivets in place. All the copper weapons except the spearhead were analysed for major elements: the technique used is referred to in a reference. All were almost pure copper except for the presence in 4 of the objects of, respectively: sword 2% tin, spearhead 0.2% tin, spearhead 0.5% antimony and javelin 0.03% antimony.

MJH

Wilhelm P Bauer: Materials from a workshop of the Kami in Nepal. *Archiv fur Volkerkunde, 1973, 27, 1-3. (In German).*

Copper and materials for soldering and welding used by a group of countrysmiths in Chautara near Katmandu are examined. Gilding materials used by the Newar tribe in the Katmandu valley are also reported. WPB(AA)

William G Dever: MB II A Cemeteries at Aimes-Samiyeh and Sinjic. *Bulletin of the American Schools of Oriental Research, 1975, (217), 23-36.*

The cemeteries at these two sites date originally from the MB 1 period, but the shaft tombs were often re-used in later periods, including MB II A. Two groups of bronze weapons and ceramic vessels from the site are described, including an important bronze find of a fenestrated crescentic axehead ('duck-bill'). A spectrographic analysis of the axe shows it to be a bronze rich in tin (14.77%), with lead (0.772%), arsenic (0.49%), and seven other measured trace elements. A small but notable feature of the catalogue of the ceramics is the use of Munsell soil colour charts to describe the pottery fabric.

MJH

AFRICA

Udo S Kusel: 'Primitive' iron smelting in the Transvaal. *Studies by the Nat. Cultural Hist. and Open-air Mus. Pretoria, 1974 (3), 20 pp.*

Describes four types of furnaces in use from 1820 to 1930. Regrets that working details have been lost due to failure to record demonstrations that have taken place in the last 40 years. Detailed construction drawings are given.

RFT

J Mishara and P Meyers: Ancient Egyptian silver: a review. *In Book:– Recent Advances in Science and Technology of Materials, Vol. 3 (Cairo Solid State Conf. II, 1973). Plenum Press, New York and London, 1974, 29–45. Tables, 52 refs.*

A review of the literature on Egyptian silver was undertaken to obtain information on the sources of the silver used for the manufacture of ancient Egyptian silver objects. Technical studies, translations of ancient Egyptian records, philological discussions, geological publications and archaeological reports provided evidence for both the importation of silver (probably produced in Anatolia or Persia from argentiferous galena ores) and the use of local silver, most likely obtained in the native form from the silver rich gold deposits in Egypt. Objects made from this silver are characterized by high gold content. Analysis was by neutron activation.

AA

Hanna Jedrzejewska: A corroded Egyptian bronze: cleaning and discoveries. *Studies in Conservation, 1976, 21 (3), 101-114. 15 figs. 17 refs.*

A very heavily corroded Egyptian bronze statuette of Amon, was cleaned by handpicking and found to be composed of six separately cast parts: two elements of head, two arms, the torso with legs, and the beard. Such cases do not seem to be unusual but are rarely observed because of beautifully concealed joins. Technical details of the mechanical methods of cleaning are given and some critical comments included on chemical and electrolytic methods: it has to be remembered that cleaning is an irreversible process. Attention is also given to analytical problems in heterogeneous objects such as this.

AA

J Ogden: The so-called 'platinum' inclusions in Egyptian metal work. *Journal of Egyptian Archaeology, 1976,* 62, *138-144.*

The hard metallic inclusions often found in Egyptian gold objects are shown to be mainly composed of osmiridium (natural alloy of osmium and iridium) with occasional small amounts of platinum, rhodium and ruthenium. They tend to be exposed at the surface because of removal of the softer gold alloy by abrasion and may be more concentrated in the part of the object which would have been lowest when cast due to their greater density. One map shows the distribution of known gold-bearing regions in Sudan and Ethiopia, and seven photographs illustrate objects with osmiridium inclusions.

MRC

H M Friede and R H Steele: Tin mining and smelting in the Transvaal during the Iron Age. *Journal of the South African Institute of Mining and Metallurgy, July 1976,* **76** *(12), 461-470. In English.*

The archaeological and metallurigcal evidence on early tin mining and smelting in South Africa is reviewed. Analyses of samples of tin ore, slag, and ingots are reported. A small experimental tin-smelting furnace is described which was constructed and worked according to African iron age technology.

MG

AMERICA

Heather Lechtman: A metallurgical survey in the Peruvian Andes. *J Field Arch. 1976,* 3 *(1), 1-42.*

Describes and identifies early metallurgical sites including mines, ore dressing areas, and smelting installations. Coastal and highland sources of copper ores were identified along the N Coast and bordering on Lake Titicaca. Evidence was found that sulphide ores were smelted long before the arrival of the Europeans.

Concludes that there is no source of arsenical mineral on the coast but plenty of copper sulpharsenides in the N Sierra. A clay bar mould was found and lead oxide ingots connected with silver processing. All manner of fuels seem to have been used including dung and grass. Some analyses of ores and metal artifacts.

RFT

Heather Lechtman, L A Parsons, W J Young: Seven matched hollow gold jaguars from Peru's early horizon. *Studies in Pre-Columbian Art & Arch. No. 16 Dumbarton Oaks. Harvard, 1975, 46 pp.*

The seven jaguars came from museums in N and S America and from Europe. They were made, in the same workshop, of sheet gold containing 8.9% Cu and 14.9% Ag. The surfaces were enriched in gold from 76% to 84% Au possibly by pickling during fabrication.

Each is composed of 12 pieces shaped by hammering over a pattern. Two types of join were used. In the first, the alloy is the same as in the parent metal (above) and its melting was assisted by the use of thin intermediates. In the second the normal 52% Ag – 48% Cu brazing metal was used with a lower melting point.

RFT

H Lechtman and M E Moseley: The Scoria at Chan-Chan metallurgical deposits. *Nawpa Pacha. 1972-74 (10-12) 135-170. (Inst. of Andean Studies, Berkley, California 1975).*

The slag on this Chimu Peru site had long been thought to be connected with metal working; it clearly results from burnt buildings and the composition is much the same as the adobe brick of the area. The plant fuel was either stored in the building or formed part of the roofing. RFT

Clyde A Sanders and Dudley C Gould; History cast in metal: the founders of North America. *Book. American Foundrymen's Society, Des Plains, Illinois, USA, 1976, 562 pp.*

Volume one of a two-volume history concentrates on metal casting in America up to about a century ago and uses material from primary sources, including photographs and drawings.

MG

J Kimberlin and J T Wasson: Comparison of iron meteoritic material from Ohio and Illinois Hopewellian burial mounds. *American Antiquity, 1976,* **41** *(4), 489-491.*

The authors have analyzed 500 iron and stony-iron meteorites by neutron activation analysis for Ni, Ga, Ge and Ir and state that they have been able to define a classification system for metal-rich meteorites. The data are not given in this paper but a reference to an earlier paper is given. An artifact from a Hopewellian mound in Havana, Illinois was analyzed and the results were compared with those from meteoritic material from a later Hopewellian burial mound in Ohio which has been identified as identical in composition to the Brenham, Kansas stony-iron meteorite. The compositions of the artifact from Illinois and those from Ohio were distinctly different and support an earlier suggestion that the sources of meteoritic metal should change with time.

JSO

TECHNIQUES OF EXAMINATION AND MANUFACTURE

M J Graham and M Cohen: Analysis of iron corrosion products using Mossbauer spectroscopy. *Corrosion, 1976,* **32** *(11), 432-438.*

Mossbauer spectroscopy is summarised and its potential in the identification of the variety of iron corrosion products found in different environments is outlined. The technique complements more conventional methods of analysis of corrosion products but its capacity is illustrated by the identification of $\Delta - Fe_2O_3$ and Fe_3O_4 which are difficult to distinguish by x-ray diffraction but which are readily resolvable by Mossbauer spectroscopy.

NHT

C Mancini and P Petrillo Serafin: Identification of ancient silver-plated coins by means of neutron absorption. *Archaeometry, 1976,* **18** *(2), 214-17.*

The differentiation of ancient Greek and Roman silver-plated coins from pure silver coins by neutron absorption is described. The apparatus used in the analysis is also described.

AATA

P A Schubiger and O Mueller: Trace elements in ancient silver coins by neutron activation and solvent extraction with bismuth diethyldithiocarbamate. *Radiochem. Radioanal. Lett. 1976,* **24** *(5-6), 353-61.*

A procedure is described for trace element analysis in ancient Greek silver coins by using radiochemical neutron activation and solvent extraction. Solutions of silver coins were extracted with bismuth diethyldithiocarbamate. The major and minor elements Ag, Cu and Au are extracted into the organic phase, whereas the trace elements Na, Mn, Co, Ni, As, Sn, Sb and Ir remain in the aqueous phase. The activities of the elements are counted on a Ge(Li) well detector and compared to those of a sample. Chemical yields are determined by postactivation.

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E G Thomsen and H H Thomsen: Drawing solid wires through soft dies in antiquity. *Journal of Engineering for Industry (Trans. of the Am. Soc. of Mechanical Engineers, Series B), Feb 1976,* **98** *(1), 211-216.*

It is shown on theoretical as well as experimental grounds that it is possible to draw solid wires of silver or gold to a diameter of about 0.3 mm or smaller by the use of soft dies of the same metal. It is argued that the fact that no such dies have been found, or recognized, in archaeological excavations may be ascribed to the possibility that the ancient goldsmith may have remelted the precious dies for other uses.

MG

Ralf-Friedrich Voss: The variants of the torsional pattern of twisted damascening. Part II. *Neue Museumskunde, 1976,* **19** *(4), 277-284. (In German).*

A description is given of how different patterns of twisted damask are produced, ie. by forge welding together various strips of damask steel, by interrupting twisting, partially under a simultaneous change of the direction of rotation, and by abrading the twist bar. The author explains the structure and significance of damascened blades. The article is concluded by a graphic survey of the different processes involved in producing the patterns of twisted and forge welded swords and other weapons of Western Europe manufacture.

AA

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