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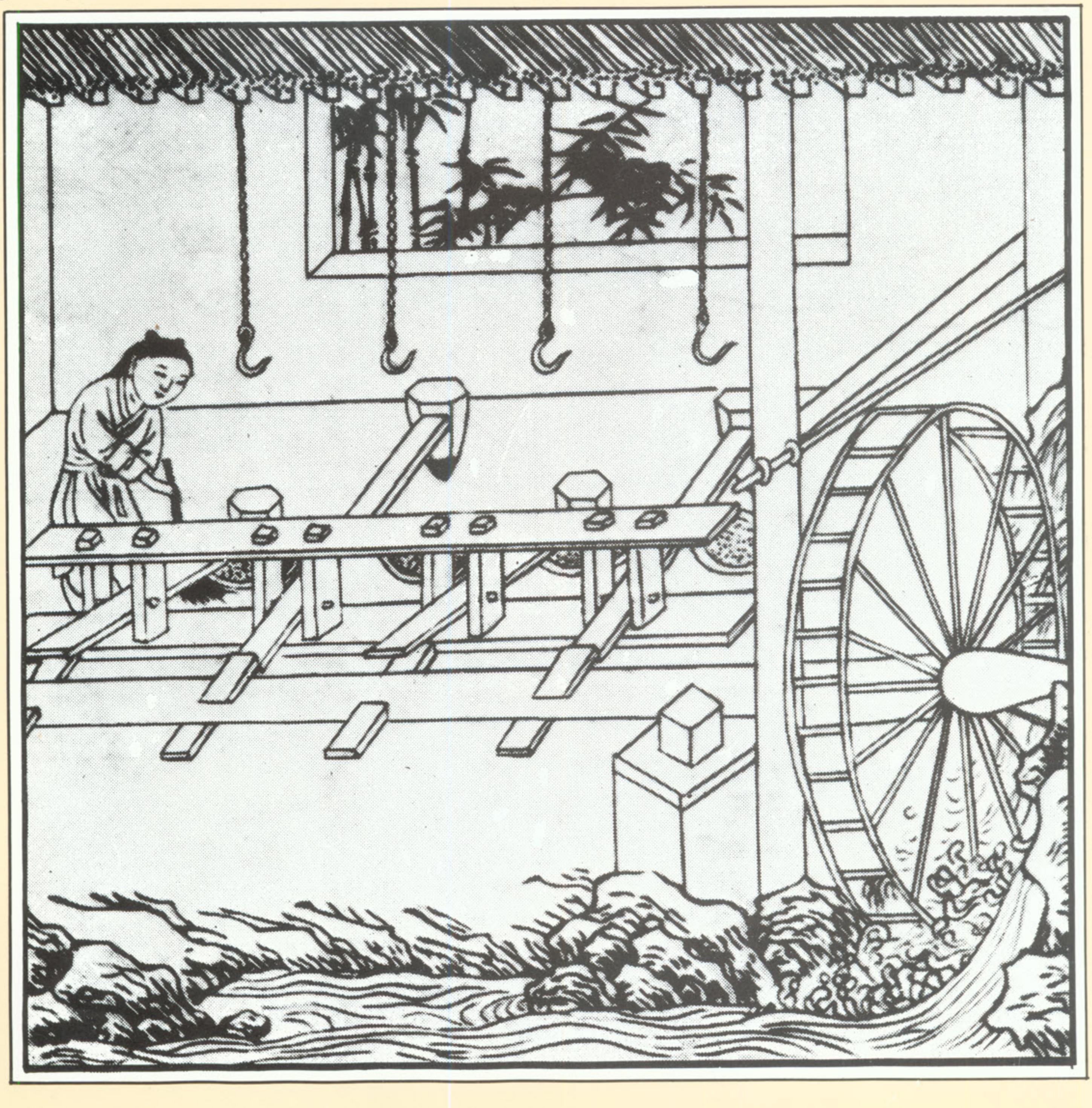

Journal of the Historical Metallurgy Society

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Owing to the unusually long list of contents, the usual HMS addresses, notes and credits appear on page 62. Notes on the cover illustration also appear there.

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Iron smelting in Western Africa: Ivory Coast

Sandra Zacharias and Hans-Gert Bachmann

In 1974 Eckert witnessed iron smelting as it was at that time still practiced in Northern Ivory Coast by the Senufo tribe at the village of Koni, situated 16 kilometers north of the provincial town of Korhogo[1,2]. Not only did he give a vivid report of all the activities connected with the local process of making bloomery iron, he also collected mining and smelting tools and sampled a selection of ores and slags, which he subsequently presented to the German Mining Museum at Bochum. Through kind co-operation of Dr G Weisgerber of the said museum we were able to study some of these remains from a well-documented pre-industrial African smelting site.

The Smelting Process

According to Eckert[1,2], lateritic iron ores have been mined in the vicinity of Koni for many generations. The clayey ores were concentrated by washing. About two thirds of the clay matrix had to be removed to obtain a sufficiently rich concentrate, which was then mixed with loamy soil and shaped into spheres with diameters of about 5 centimeters which were left to dry.

The construction of the shaft furnaces for smelting took about two months. A hole was dug into the ground (about 50 centimeters deep and 150 cm wide) which was afterwards fitted with a lining about 30 centimeters thick, consisting of clayey soil tempered with straw. The same mixture was used to make the tuyeres. After leaving the foundation of the furnace to dry for about a week, the furnace wall was built up to a height of about 80 centimeters. In stages several more sections were added to the shaft. As a final step a collar-shaped roof-shelter was constructed around the furnace proper (Fig 1). Two weeks after finishing the construction, a charcoal fire was ignited inside the furnace and kept burning for two days. After cleaning out the ashes the furnace was ready for use.

Each furnace had a life span of four to six years with annual repairs to the roof. To catch the prevailing winds, the furnace openings were orientated towards the west. Three sizes of furnaces were in use at Koni; the largest could smelt about 200 spheres of ore, the medium size 90, and the smallest 80. Charcoal was produced by the Koni smelters themselves in the vicinity of the village.

A smelting run started with a radial arrangement of six tuyeres above the furnace bottom. The front part of the furnace, through which the bloom had to be extracted at the end of the run, had first to be temporarily closed. The preheating of the furnace was done with straw. At the end of this preliminary operation, the tuyeres were firmly fixed in position with clay fettling and the front hole was closed. With burning charcoal added to the heated furnace, a charge of about 130 spheres of ore was fed into the furnace within an hour. In alternate layers further charcoal and ore were thrown in. After several hours of operation the tuyeres had to be cleaned with an iron rod. The fire was kept burning overnight. The whole smelting process took about 20 hours. Slag was not tapped. At the end of the run, a bloom weighing from 15 to 35 kilograms was extracted after the front opening of the furnace had been broken open. The blooms had to be cleaned of adhering slag with appropriate tools. They were either sold as such or crushed to reclaim the metallic iron droplets embedded in the slag matrix.

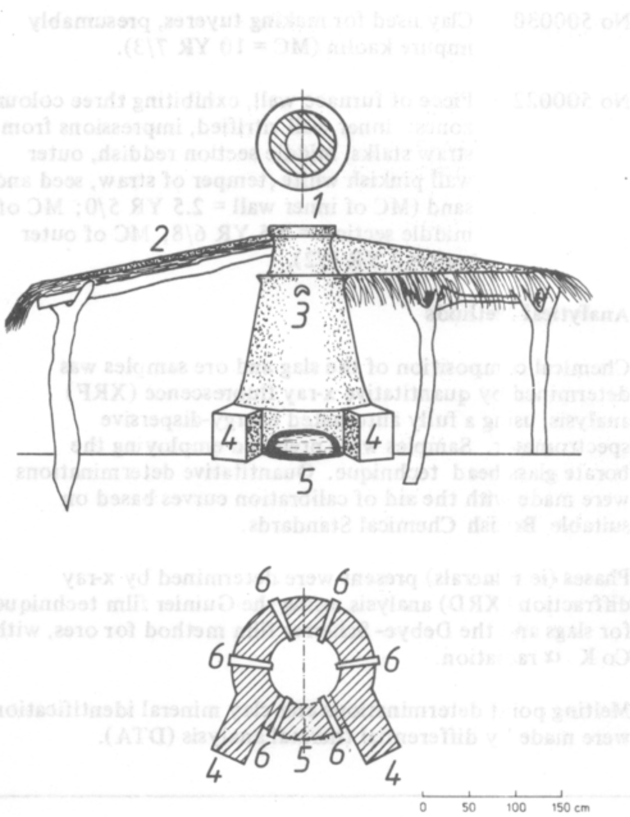


Fig 1 Bloomery furnace from Koni/Ivory Coast (after Eckert[2])
Explanations: 1) top opening of shaft furnace; 2) charging platform made of branches, straw and earth, 3) hole in furnace wall to control charge level, 4) supporting steps, 5) extraction hole, 6) tuyeres.

Sample Description

The collection we were able to investigate consisted of the following samples (MC = Munsell Colour[3]; slags and clays: powder, ores: streak):

No 500014:	Furnace slag, flow marks present, two phases visible: glassy and porous crystalline, inclusions of small rock fragments on one face and carbonised straw stalks throughout (MC = 5 Y 6/1).
No 500021:	Slag drip from tuyere, homogeneous, porous, glassy appearance (MC = 5 Y 5/1).

No 500039: Slag, concave-convex in shape, resembling smithing slag, colour variable, inhomogeneous, porous structure, no flow marks.

No 500027: Washed ore, fine grained (MC = 2.5 YR 3/2).

No 500028: Ore charge, ie washed ore mixed with clay (MC = 5 YR 6/6).

No 500030: Clay used for making tuyeres, presumably impure kaolin (MC = 10 YR 7/3).

No 500022: Piece of furnace wall, exhibiting three colour zones: inner wall vitrified, impressions from straw stalks, middle section reddish, outer wall pinkish white, temper of straw, seed and sand (MC of inner wall = 2.5 YR 5/0; MC of middle section = 2.5 YR 6/8; MC of outer wall = 5 YR 8/2).

Analytical Methods

Chemical composition of the slag and ore samples was determined by quantitative x-ray fluorescence (XRF) analysis, using a fully automated energy-dispersive spectrometer. Samples were prepared employing the borate glass bead technique. Quantitative determinations were made with the aid of calibration curves based on suitable British Chemical Standards.

Phases (ie minerals) present were determined by x-ray diffraction (XRD) analysis, using the Guinier film technique for slags and the Debye-Scherrer film method for ores, with Co K α radiation.

Melting point determinations and clay mineral identifications were made by differential thermal analysis (DTA).

Viscosity coefficients were calculated for slags, using a formula that expresses the relationship between the 'acidic' and 'basic' oxides present in the slag[4]:

$$\text{Viscosity} = (FeO+MnO+P_2O_5+K_2O+CaO)/(Al_2O_3+SiO_2)$$

The results of these investigations are summarised in Table 1.

Discussion

The high quality ore concentrate of magnetite and hematite was slightly 'diluted' by the addition of clay to form spheres suitable for charging. The addition of clay increased the otherwise low concentrations of alumina and silica in the ore, while the lime content remained constant. No further fluxes were added during the process. The slag sample representing a typical bloomery slag is specimen No 500039 B, consisting of fayalite and wustite. Sample No 500039 A – a different portion from the same inhomogeneous slag cake – has a similar chemical composition. Its mineral content with quartz and wustite as the dominating phases and spinels and fayalite as additional ingredients is somewhat different but still falls within the category of 'genuine' bloomery slag. Both specimens exhibit manganese contents greater than those found in the ore. This is puzzling unless one assumes that manganese oxides – which defy reduction in the bloomery process – tend to become concentrated in the slag. On the other hand, the ore concentrates may perhaps vary in their manganese contents and the ones analysed could have been exceptionally low in this element. The lime contents in these two slag samples are also higher than those found in the ores. This is either due to an uptake of lime from charcoal ashes and/or lime from the furnace lining.

The remaining specimens Nos 500014 and 500021 are

Table 1: Slags and ores from Koni/Ivory Coast; Analytical Data

Sample No.	Description	SiO_2	FeO	MnO	CaO	MgO	Al_2O_3	TiO_2	K_2O	S	Mineral Content	Viscosity Coefficient	Melting Point
500014	Furnace slag	41.1	21.6	0.4	22.2	0.4	10.2	0.5	0.5	0.1	FAY,SP,WU	0.880	1160°C
500021	Slag drip for tuyere	36.9	28 9	0.4	17.3	-	10.5	0.5	0.7	0.2	FAY,SP,WU,WO	0.996	1190°C
500039A	Slag cake inhomogeneous	32.9	41.5	2.1	2.6	-	8.3	0.3	0.3	-	Q,WU,SP,FAY	1.127	n.d.
500039B		41.6	41.0	4.5	4.4	-	4.7	0.6	0.4	0.1	FAY,SU	1.087	n.d.
500027	Washed ore	5.3	85 3	0.4	0.3	-	3.6	0.1	0.1		MAG,HEM		
500028	Ore charge (ore + clay)	14.1	70.3	0.3	0.3	-	9.9	0.2	0.1	-	MAG,HEM		

Abbreviations:-

FAY = Fayalite, Fe_2SiO_4
SP = Spinels, eg $FeAl_2O_4$, Fe_3O_4
WU = Wustite, FeO
WO = Wollastonite, $CaSiO_3$
Q = Quartz, α-SiO_2
MAG = Magnetite, Fe_3O_4
HEM = Hematite, α-Fe_2O_3
n.d. = not determined

slags contaminated with components from the furnace lining. Lime contents of about 20 percent cannot be accounted for otherwise. The FeO-contents are correspondingly low.

Among the minerals identifiable by XRD, the most prominent are fayalite (Fe_2SiO_4), wustite (FeO), and the spinels, hercynite ($FeAl_2O_4$) and magnetite (Fe_3O_4). In one of the lime-rich slags, a small amount of the calcium silicate, wollastonite, ($CaSiO_3$) could be discerned. Quartz is present in one of the slags as a separate phase, which was most likely introduced into the furnace charge by the sandy clay with which the ore concentrates were mixed prior to smelting.

As XRD is unable to detect amorphous glass, the question of presence of glassy constituents in the slags has to remain unanswered; but some percentage of glass is highly probable, particularly in the two slag samples exceptionally high in lime.

The low viscosity coefficients point to low fluidity (ie high viscosity) of the slags. Therefore, the absence of tap slags is not surprising. The operating temperature of the furnace as deduced from the two melting point determinations on slags must have been in the vicinity of 1200 to 1300°C, which is quite normal for bloomery furnaces. It should be borne in mind that these temperatures were achieved by induced draught (no bellows!) through six tuyeres and the chimney-effect of the shaft furnace. About 60 percent of the iron content of the ore charge was lost in the slag, a percentage accounting for reasonably good efficiency of the bloomery process as it was practised by the Senufo tribe.

References

1 H - E Eckert: Urtumliche Eisengewinnung bei den Senufo in Westafrika. Anschnitt, 1976, 28, 50-63.

2 H - E Eckert: Eisengewinnung bei den Senufo in Westafrika: – 1974; in: Eisen und Archaologie; Eisenerzbergbau und – verhuttung vor 2000 Jahren in der VR Polen, Katalog zur Austellung im Deutschen Bergbau-Museum Bochum 1978, 94-107.

3 Munsell Soil Color Charts, 1971. Munsell Color Division, Baltimore, Maryland, USA.

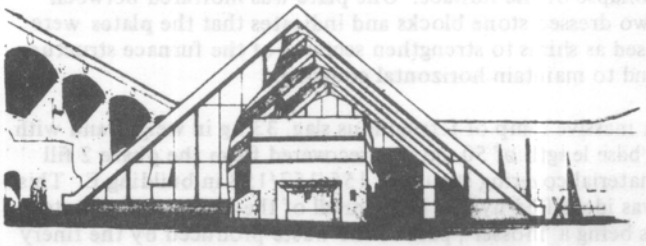
4 H G Bachmann: Early Copper Smelting Techniques in Sinai and Negev as Deduced from Slag Investigations; in: Scientific Studies in Early Mining and Extractive Metallurgy. British Museum Occasional Paper No 20, London 1980. 103-134.

A new cover for the Old Furnace

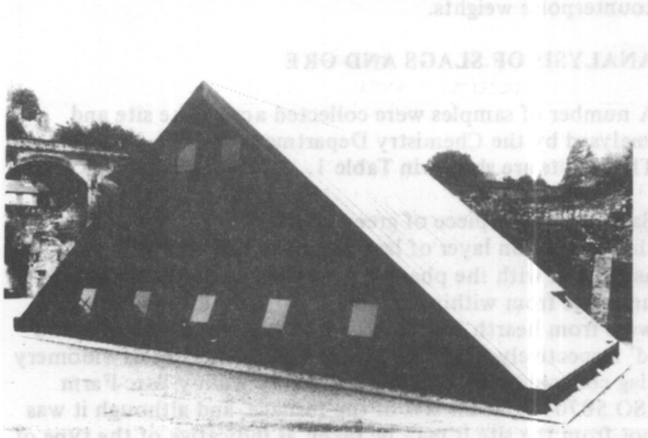
It is interesting that a feature of the Koni furnace is the conical shaped roof as one of the most important conservation developments to be completed during 1982 was the provision of a cover building for the historic Old furnace at Coalbrookdale.

On 27th July 1982 HRH the Duke of Gloucester visited the Ironbridge Gorge Museum complex and officially opened the new structure, which is designed to protect the furnace in which Abraham Darby I first successfully smelted iron with coke in 1709, from further deterioration.

Finance for the project, which was estimated to be in the region of £165,000, was provided by the National Heritage Memorial Fund, the Department of the Environment, the National Coal Board and the Manpower Services Commission and the work which began in the Summer of 1981 was completed during Spring 1982.



The new Cover Building at Coalbrookdale



Excavations at Abbey Tintern Furnace

John Pickin

PART II. THE FINDS

4.1 POTTERY

A small amount of eighteenth-century pottery was recovered from the site, and all was found in a phase 2 context. It has been identified by J M Lewis of the National Museum of Wales as having Bristol affinities, with the most common types being combed slipwares and North Devon gravel-tempered wares.

4.2 MOULDING SAND (Fig 16)

Forty three pieces of vitrified moulding sand were recovered from layer in the 10m x 2m trench excavated E of Area 2 (Figs 8 and 12). All the pieces retained a negative impression of the object being cast and a number of objects were represented. The pieces were too small to allow detailed reconstructions but the curved, carinated aspect of many of the pieces suggests the casting of cylindrical objects such as cooking pots.

4.3 IRON OBJECTS (Fig 17)

Two pistol lock plates, one with the associated hammer and flash pan, were found in the floor layer of building F. They were identified by the Welsh Regimental Museum as late eighteenth century in date and belonging to a horse pistol. The occurrence of two lock plates independent of a pistol suggests that they were spares.

Five semi-circular cast iron plates, 35 cm in diameter and 1.50 cm thick were found in the rubble associated with the collapse of the furnace. One plate was mortared between two dressed stone blocks and indicates that the plates were used as shims to strengthen sections of the furnace structure and to maintain horizontal coursing.

A massive lump of ferruginous slag, 33 kg in weight and with a base length of 50 cm was recovered from the phase 2 fill material covering structure 155/157/158 in building E. This was identified by J G McDonnell of the University of Aston as being a 'mosser', part of the waste produced by the finery and chafery process. It would seem (see para 5.9 below) that this part of building E was the counterpoise recess for the bellows and it is tempting to see this object as one of the counterpoise weights.

4.4 ANALYSIS OF SLAGS AND ORE

A number of samples were collected across the site and analysed by the Chemistry Department of BSC, Llanwern. The results are shown in Table 1.

Sample 1 was a piece of green coloured furnace slag from the foundation layer of launder pillar 118 and was associated with the phase 2 ground extension; sample 2 was hematite from within building C, Area 1; samples 3 and 4 were from hearth 231 in Area 2 and relate to layers 'a' and 'd' respectively (Fig 12b); sample 5 was a piece of bloomery slag collected from the North Field at Wain-y-Parc Farm (SO 507015), 2 km NW of the furnace, and although it was not from the site it may be taken as indicative of the type of 'cinder' used in the charge.

Table 1

Analyses of Slags and Ores (%)

	1	2	3	4	5
	Slag	**Ore**	**Slag**	**'Slag'**	**Slag**
$Fe0$	2.17	0.39	44.16	17.98	44.65
Fe_20_3	0.33	97.40	21.06	11.19	14.57
$Si0_2$	48.90	0.78	21.53	55.67	27.21
Al_20_3	8.31	0.26	1.56	6.38	5.52
$Ca0$	30.69	0.35	2.09	2.93	3.40
$Mg0$	4.97	0.16	0.49	0.61	0.96
P_20_5	-	-	2.49	0.51	0.24
$Mn0$	0.46	0.03	3.52	0.65	0.19
$Ti0_2$	0.40	-	0.40	0.33	0.26
K_20	2.50	-	0.69	1.40	1.63
C	0.10	0.09	0.97	0.01	0.42
S	0.10	0.005	0.052	0.01	0.010

Professor R F Tylecote comments on the analyses as follows:

Sample 1:	the high K_20 value suggests charcoal not coke smelting. The very high lime content could indicate hot blast but as this process is excluded by the date of the site it shows, instead, a good practice.
Sample 2:	the high Fe_20_3 content suggests a Cumbrian source. As Beckermet and Lancashire ores today tend to have a high silica content, it is possible, therefore, that this sample came from Eskdale.
Sample 3:	this is a forge slag with some woodash in it. The phosphorus content precludes Cumberland or Forest of Dean ores.
Sample 4:	this is merely woodash with some slag in it.
Sample 5:	the values are consistent with a typical bloomery slag.

This article is the second part of the Excavation Report which commenced publication in *JHMS 16/1 1982.* Figures 16 and 17 continue the numbering sequence started in that issue and we have repeated Figure 3 for the convenience of readers.

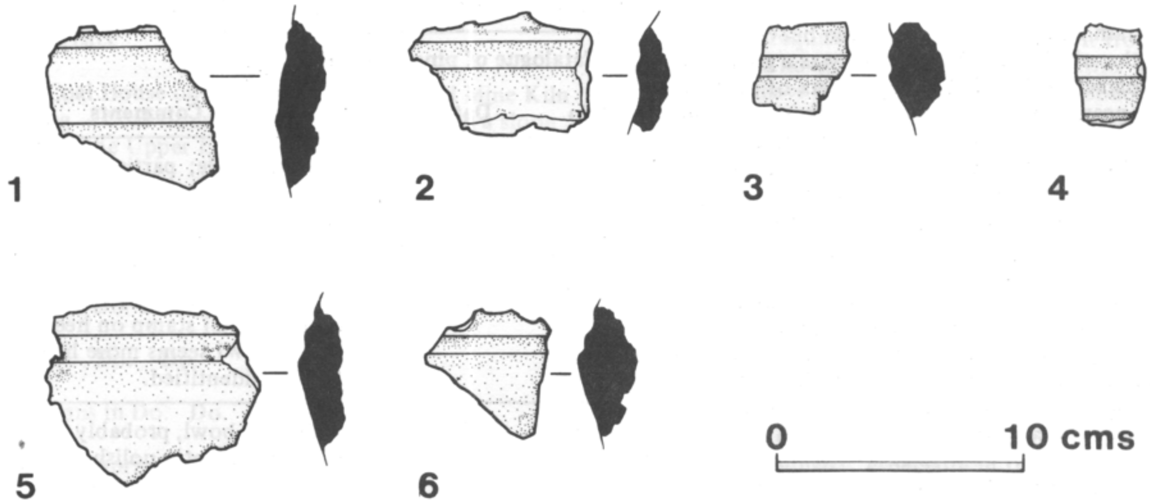


Fig 16

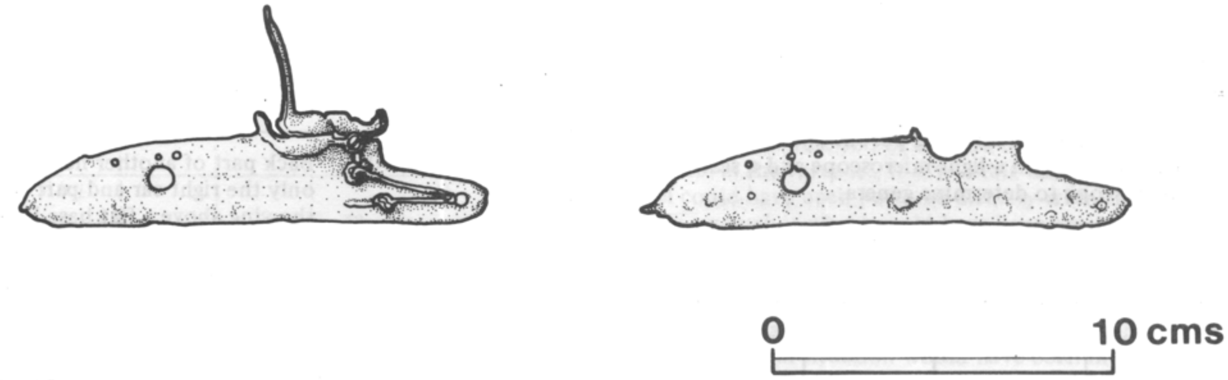


Fig 17

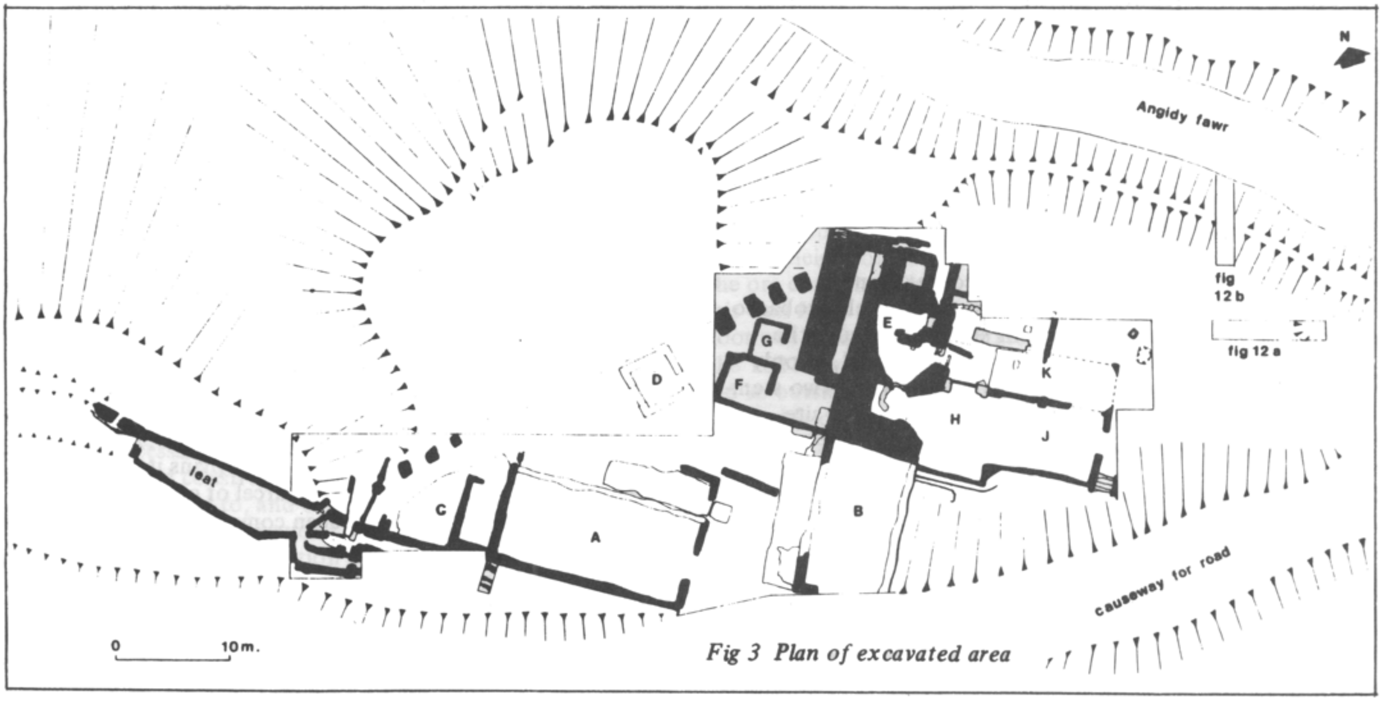


Fig 3 Plan of excavated area

4.5 CAST IRON *by R F Tylecote*

A piece was cut from the edge of one of the cast iron plates which covered drain 162 (Fig 8). It had been heavily oxidised nearly the whole way through and was a grey cast iron with very coarse graphite flakes in a matrix of pearlite and ferrite. The pearlite was very coarse which is symptomatic of very slow cooling. There was also some phosphide eutectic which, it is usually found, is the last phase to oxidise so it can be seen as residual islands in the oxide layers. There was no manganese sulphide. The hardness of the matrix was 215 HV1.

I would suggest that this has 'grown' due to high temperature oxidation which has attacked first the iron, then the graphite and finally the phosphide. This growth process can be caused either by corrosion or high temperature oxidation. It could have formed a fireback or hearth plate and after its final heating was slowly cooled.

The phosphorus content would suggest that it did not come from the ores of the Forest of Dean.

4.6 CHARCOAL *by M Elliot*

Charcoal samples were taken from four areas on the site. Sample 1 came from the clay floor to the E of Building F; sample 2 from pit 17 in Building A; sample 3 was collected from the phase 2 fill forming the foundation layer for launder pillar 118; sample 4 came from the phase 2 fill above wall 160 in Building E.

The charcoal was divided into ring-porous and diffuse-porous types and examined with a light microscope and a scanning electron microscope to determine genera:

Area			
1	2	3	4
Oak	Oak	Oak	Spindle-tree
Ash	Ash	Lime	
Beech	Alder		
Horsechestnut			

The charcoal study was made with the help of the Botany Department of Bristol University.

4.7 CLAY TOBACCO PIPES *by D F Markell*

All the pipes came from unstratified contexts and it is perhaps surprising that such a small amount of clay tobacco pipe material was produced by this site. As a result, the quantity submitted for report, consisting as it did, of only two bowls, three part-bowls, one marked heel and two stem-pieces, was far too small to be of any real value for site-dating purposes.

The overall time-span covered by the material is approximately 200 years, from 1660 to the late 19th century, half of it being from the latter end of the period.

While both Broseley and Bristol-style products are represented in the 17th/18th century items, it is not possible to be definite about the sources of the later material as by this period, regional styles having ceased, practically identical pipes were being produced throughout the country. However, Bristol or Gloucester are suggested as the most likely places of origin.

Catalogue of pipe material

No.	Dating	Comments
1	1660-80	Broseley style; partially milled; not very well-finished bowl; slightly flared, lop-sided oval heel, no mark.
2	1680-1720	Broseley style; heel only, flared, kite-shaped, probably Atkinson's type 5; relief stamp on heel is not clear but WI seems more likely than NI; – unidentified.
3	1730-50?	Plain part bowl, probably Bristol type; apparently polished originally but surface now chipped and cracked; spur missing, no mark. Dating is approximate only.
4	1800-20	Part bowl only; decorated with alternate thick and thin flutes, stylised oak leaves on the back, front missing. Fairly thick wall, no mark.
5	Post 1850	Smallish bowl in the shape of a head which is moustached and possibly bearded and wearing a form of turban.
6	Post 1850	Back part of another head-shaped bowl only the right ear and part of the hair showing above a flat base looking like a possibly military tunic collar carrying a 'rosette' and other decorative elements.

5.1 INTERPRETATION OF FEATURES

A functional interpretation of the various features excavated on the site can be made using the archaeological evidence itself, contemporary documentation that relates to the site, and comparative evidence, both physical and historical, from similar furnaces.

The archaeological evidence has been outlined in the preceding sections. The historical evidence (section 2) provides a certain amount of information about the economics and management of the furnace but provides little that can be used to aid an understanding of the physical layout and function of the site. Only two contemporary plans are known to exist: the earliest is dated 1763 and was made by John Aram as part of a survey of the holdings of the Duke of Beaufort in the parish of Chapel Hill. The second plan is from 1821 and accompanied an inventory of stock at the furnace[2]. Both plans show a ground layout similar to that excavated but do not identify individual buildings. The only noticeable difference between these plans and the present layout is the course of the river east of the site. The modern river runs parallel with the road while on the contemporary plans it circles away from the road to enclose the parcel of ground known as the 'Cinder Bank'. This has been commented upon by Paar and Tucker[2].

The inventory which accompanies the 1821 plan is of interest as being the only list of fixed stock and associated buildings at the furnace[2]. For this reason it is reproduced below in full:

Blast Furnace

Upper Coal House on southside the Road and Mine Kiln adjoining – Coal House on the North side with a slope or shed at the Upper End.

Stampers

1 Water Wheel and Shaft

2 Rings on Do. Cast Iron

12 Cams – Do. Do.

2 Gudgeons in Do. Do.

2 Cast Iron uprights for Stamper Helves to work in about 12 cwt

An Office for the Furnace Stocktaker

A Charcoal Shed near the Office

Blast Furnace Stack Bridgehouse and Casting House, the Furnace without a Hearth

Blast Furnace machinery consist of 1 water wheel, 2 cylinders, 1 regulator and blast pipes as far as the bag.

An undated and unsigned watercolour in Chepstow Museum (CH 1956 : 5) entitled 'Ironworks at Tintern' may show the water wheel and blowing house at the furnace. This is discussed below (Fig 18).

5.2 THE LEAT (Fig 4)

The leat itself would appear to be self explanatory in both phases. The only puzzling feature is the increase in its width to the NW of the entrance to the secondary leat. The most likely explanation for this would be that as this leat served both the furnace wheel and the secondary leat, it was necessary to have some form of holding or terminal pond to store water, presumably regulated by a series of sluice gates (ie 42 ,52 and 56).

The secondary leat presents more of a problem, as there was no direct archaeological evidence to indicate its purpose. As it respected the phase 1 leat, and was respected by the phase 2 leat, it can be assumed that it was in operation throughout most, if not all, of the working life of the site. From the archaeological evidence, and from the ground evidence beyond the excavated area, it is apparent that it carried water from the main leat in the area of the holding pond down slope to the river. If this is accepted then the most plausible explanation would be that it acted as an overflow, but if it was simply an overflow then all that would have been necessary would have been a breach in wall 34. The complicated construction of this watercourse whereby it is directed parallel to, and culverted beneath ,the main leat indicates a function beyond that of a basic overflow channel. A possible explanation could be that this secondary leat represents part of a washing floor or buddle. Schubert[9] (308) gives a number of instances of washing and cleaning ore at British furnaces but this process would not have been needed if hematite was used, and especially if calcining took place. It is not known what proportion of the charge was in the form of bloomery slag. At Coed Ithel it may have represented the majority, if not all, of the charge[7] . It would have required washing to separate it from earthy materials, although it is questionable whether washing of slag would have taken place where it was collected or where it was delivered. A more probable explanation is that the secondary leat acted as a power source. The 1821 inventory refers to a second wheel of unknown diameter which operated a set of stamps. Stamps for ore crushing were in use at a number of furnace sites by the early eighteenth century (Schubert[9] : 311) and John Hanbury, who leased the Abbey Tintern Furnace in the first decade of that century, was experimenting with stamps at his furnace at Llanelli in N Gwent. Thus it is possible that stamps could have been used at Tintern in phase 1. At some of the furnaces in the Forest, such as Parkend and Redbrook, stamps were employed not just to break ore but also to treat the furnace slag or 'scruff', which was used in the glass industry, especially in the manufacture of the Bristol black bottle glass. Viscount Torrington who visited the site in 1781 mentioned that: 'the (slag) dross (from the furnace) is sent to the glass houses of Bristol; much is employed in the mending of roads' (Hart[14] : 158).

As it is probable that the slag would only be required in a granular or powdered form, Torrington's statement could imply the use of stamps at Tintern furnace for breaking it. There was no archaeological evidence to suggest the position of the stamps. If they were erected to treat slag and had had no previous function, then the most likely position would have been at the east end of the site to allow the easy transport of slag from the furnace. It is possible that a small undershot wheel could have been powered directly from the river or that an undershot wheel could have been erected in the area of land called the 'Cinder Bank' on the 1821 plan to make use of the water from the wheel race (Fig 2 'Z'). In either case the wheel would have been outside the excavated area. If the stamps had been erected primarily to crush ore then their most logical situation would have been in the storage and charging area above the furnace and presumably powered by the main leat or an off-shoot of it. It is conceivable, then, that the secondary leat represents the power source for the stamps wheel. The culverting beneath the phase 1 leat, and the deliberate slope built into floor 20, would be necessary to create the required water flow to operate a small undershot wheel.

5.3 FLOOR 29 AND BUILDING C (Fig 4)

The presence of hematite in the pitched stone floor of 29, and the overall red and purple staining of the floor, suggests that this was an ore storage area, with Building C being a re-organisation of this storage area late in phase 2. The original height of wall 25 is not known but it is possible that the ore could have been loaded into the storage area over this wall from the roadside and that the sloping angle of the floor was designed to facilitate hand removal of the ore. The 1821 inventory refers to a 'mine kiln' south of the road and so outside the area investigated. No trace of a kiln is observable on the ground and it is interesting that neither the ore from 29 nor that found within building B shows any sign of having been calcined.

5.4 BUILDING A (Fig 5)

There were at least two charcoal houses in the top area of the site, one, the 'Upper Coal House' of the 1821 inventory, being south of the road. The large size of Building A suggests that it was probably the second coal house and extensive deposits of charcoal were found across much of the floor area and also within post holes 17, 18 and 19. As Building A was a phase 1 feature that remained in use with little change into phase 2, then its construction may not have been much later than the charcoal houses at the King's Ironworks. The original height of the building is not known but, as the south wall is built against the natural bank, it is possible that charcoal was loaded into the building from above, the doorway at the east being only for the removal of material.

The phase 2 building represented by floors 61 and 62 which was added onto the side of Building A had no obvious functional purpose and may have been no more than a secondary charcoal shed or storeroom.

5.5 BUILDING B (Fig 5)

The location of Building B directly above and behind the furnace, coupled with the occurrence of large quantities of hematite in the phase 2 floor layer, indicates that this was the Bridge House where the raw materials would have been prepared for the furnace charge. As no entrance into the building was found in the part that was excavated it must be supposed that it was situated in the SW or end wall which could not be examined as it lay beneath the modern road.

The building is essentially a phase 1 feature and forms a structural whole with the furnace. The two side walls 68 and 69 are set into the natural slope with the floor level within the building conforming to the top of the slope to SE, and the furnace mouth to the NE. The absence of a floor level cross wall at the furnace end of the building suggests that both the bridge house and the furnace were covered by one roof. The roof may have been constructed in a hipped fashion over the furnace top to allow an extended chimney to be built up from the throat so that charging could take place at floor level within the building. Both bridge and furnace would, therefore, have been contained in one barn-like building with tunnel 218 acting as a structural support arch between the two units; the internal area of the bridgehouse would have been backfilled between the natural slope and over tunnel 218 to the back wall of the furnace to form the floor level. The phase 2 ground extension to either side of the bridge house raised the external ground level to the same height as the internal floor level to create, visually, the false impression that the bridge house and the furnace top were two separate units. The large amount of sandstone tiles found within the building indicates the type of roofing material used but it is possible, in the early period at least, that the bridge and furnace were uncovered. The accounts for 1673 - 75 (HRO-F-V1-AF-3) refer to 'making a cabbon for the fillers on the furnace bridge' and this need for protection must imply an open top at this date. Initially the bridge may have been no more than the name implies and acted solely as a buttress and access way between the furnace and the natural bank.

5.6 THE FURNACE (Figs 9 and 10)

The absence of any alteration to the external form of the furnace, and its structural connection with Building B, suggests that it is a phase I feature that was in use until the end of the industrial activity on the site. The historical evidence indicates that the latest date at which the furnace could have been blown in was 1669, and its size is consistent with known furnaces of a similar date. The height of the furnace from hearth to throat is estimated to have been 7.10m which would have been around the optimum height for a British charcoal furnace, as charcoal could not easily have borne the weight of the charge in a taller stack.

The furnace could only be observed in profile along the back wall (212) and had a slightly stepped appearance, so that, on projection, the furnace top had an estimated width of 4.90m compared to the width at the base of 7.60m. This tapered profile would, presumably, have been a structural feature, and is found at the Soudley Furnace where the base width was 1.10m greater than that for the top[24]

The original height of the two furnace openings, X and Y, cannot be estimated. Some chamfered blocks of masonry were recovered from the furnace rubble in the area of the openings which may have come from the roof portions, suggesting that the roof sloped down towards the crucible; the angle of the chamfer was between 50 and 60 degrees. A 1699 reference (GRO Misc Mss 1156) to 'four sows in the furnace' implies that the openings were supported on cast lintels.

The internal form of the furnace had suffered so badly as a result of the collapse of the main furnace structure that only a portion of the tunnel lining and part of the crucible remained. As the lining and hearth would have been replaced at regular intervals the excavated remains must relate to the very end of phase 2, c.1826, and the circular tunnel, bosh and hearth is to be expected for such a date. There was no evidence to suggest the internal form of the lining during phase 1.

5.7 BUILDINGS F AND G (Fig 8)

There was no archaeological evidence to explain the purpose of these buildings. The small size and relatively poor construction of building G suggests that it may have been no more than an open store area, while building F, with its fireplace, may be a domestic structure. It is tempting to connect building F with the 'Office for the Furnace Stocktaker' listed in the 1821 inventory.

5.8 WHEELPIT (Fig 11)

The wheelpit has been discussed above (3.7 and 3.8) and the probable size and position of the wheel reconstructed. The Chepstow Museum water colour (Fig 18) referred to in 5.1, while it may illustrate another of the works in the valley, depicts a layout very similar to that of phase 2 at the furnace site. A wooden launder, supported on stone pillars, is shown at 90 degrees to the wheel which is operating machinery in the building adjacent to it. The orientation of these structures, and of the valley, coincides well with that observed on the site, and it is tempting to see the omission of buildings which would have been visible as an artistic whim.

5.9 BUILDING E (Fig 8)

The situation of building E between the wheelpit and opening Y into the furnace indicates that this structure must have housed the blowing apparatus operated by the wheel and, therefore, indicates that opening Y was the tuyere arch.

The 1821 inventory lists the blowing machinery as '2 cylinders, 1 regulator and blast pipes' which means that by this time blowing cylinders were being used. Mushet[17] claims that Abbey Tintern was the first charcoal furnace in Britain to use cylinders, and, although he does not give a date for their introduction, it is conceivable that they were in use around 1750, by which time John Wilkinson was employing blowing cylinders at his Bersham works in North Wales.

Fig 18 *Watercolour from Chepstow Museum collection. Entitled 'Ironworks at Tintern'*

Before cylinders were introduced the furnace would have been blown by bellows operated by cams fitted to an extended water wheel axle. There was no evidence to suggest the layout of the bellows but the wheel axle presumably passed through wall 114 to a bearing in the area of the masonry blocks 168 – 171 on the opposing wall of building E. The bellows would have been to the SW and two square recesses built into 130 and 132 at the hearth end of opening Y could have held a timber support for the nozzle of the bellows or the tuyere. The alcove at the opposite end of the building formed by walls 155, 157 and 158 is in alignment with opening Y and may, therefore, have housed the bellows counter-poise system.

The phase 2 alterations to the building may well relate to the change in blowing equipment. Again, the position and type of the cylinders cannot be deduced from the archaeological evidence, but it is probable that the cylinder pistons were operated by a beam connected to a crank working directly off the wheel axle or, via the wheel, by a rack and pinion gear. In either case there would have been no need for a counter-poise system and so the length of the building could have been shortened. A shortening of the building appears to have occurred with the construction of wall 163 which, by cutting off the supposed counter-poise pit (155, 157 and 158) of phase 1, became the new back wall of the building.

No holding down bolts were found to indicate the position of the two cylinders and it is possible that they rested on a timber framework. A beam slot running along the south edge of 164, and an isolated 'horizontal' post-hole in the inner face of 131, could represent such a framework.

5.10 BUILDINGS H AND J (Fig 8)

If furnace opening Y is interpreted as the tuyere arch, then opening X must have been the tapping arch, which, in turn, makes buildings H and J the cast house. The lack of excavation to any working level because of problems with the water table means that it is impossible to make any valid interpretation of the two buildings other than a general functional one. It is possible that the increase in the overall length of the cast house in phase 2 with the addition of Building J, reflects an increase in production or a change in casting techniques and the type of product being cast.

5.11 BUILDING K (Fig 8)

Building K is functionally obscure. It is a phase 2 structure and contemporary with building J, the cast house addition, and the main feature is the rectangular trench, 183, which appears to have acted as a sump for the three drains 162, 178 and 187. The purpose of this trench is unknown and it is hard to connect it with any casting operations. The recovery of casting sand from the section excavated E of Area 1 shows that secondary casting, possibly of domestic utensils, was carried out on the site. If buildings H and J represent the primary cast house for pig or sow casting, then it is plausible that building J was used for secondary casting, but this could not be established through the archaeological evidence and so the function of the building must remain ambiguous.

5.12 HEARTHS 230 AND 231 (Fig 13)

Both hearths can be placed in an early part of the post-industrial phase 3. They would seem to be iron working hearths, perhaps for smithing. Local tradition maintains that the site was used for small-scale nail making after the closure of the furnace and, although this cannot be substantiated, these two hearths could have been used in a similar activity.

6 CONCLUSIONS

The excavation at Abbey Tintern has uncovered the layout of a charcoal ironworks that operated between 1669 and 1826. Although a number of similar sites exist in Britain, it is generally only the furnace stack which survives or has been excavated. For this reason, comparative evidence for the layout of associated buildings and structures is relatively poor.

In the Wye Valley and Forest of Dean only the remains of three furnaces exist today: Trellech (SO 487048), Coed Ithel (SO 528027) and Guns Mill (SO 675159). Only the stacks survive, but the external structure of all three furnaces is very similar to Tintern in both ground plan and height. An interesting feature of Trellech and Coed Ithel is that although they were both built against a natural bank to facilitate charging, the furnaces themselves are free standing. This suggests a timber bridge and a separate bridge house. At Tintern there is a stone bridge with a bridge house that covers both the bridge and furnace top, and Guns Mill follows a similar pattern. This change in design may be explained by the earlier date for Trellech and Coed Ithel (mid-17th century), as the free standing furnace is paralleled at other furnaces of a similar date such as Rockley or Sharpley Pool, which were both blown in in 1652 [23]. The present furnace at Guns Mill was in operation by 1683, and it may be that by that time the solid or stone bridge had become an accepted part of the furnace design. A variation of this can be seen at Charlcot in Shropshire where the furnace is joined to the bank with an earth and rubble causeway bridge; Charlcot was blown in c.1712.

The ground plan and external structure of Tintern Furnace compares favourably with other 17th century examples, both locally and nationally. The original shape of the furnace's internal lines is unknown, but as the first round-sectioned shaft was Yarranton's furnace of 1652 it is not inconceivable that Tintern had a similar shape when blown in. However, Trellech, Coed Ithel, and Guns Mill all have a square section stack which may indicate that this shape was used locally until quite a late date; Guns Mill was blown out c.1732.

The lining which survives at Tintern shows a circular stack, bosh and hearth, but this must date from the last period of use, and comparison must be sought with furnaces of the late 18th and early 19th centuries. By that period the round shape was in use at all British charcoal furnaces, and the bosh diameter at Tintern of 2.45 m is not dissimilar to the bosh diameter of 2.75m at Eglwysfach furnace in Dyfed.

Evidence for the arrangement of blowing cylinders at charcoal furnaces is poor. Excavations at Bonawe in Argyll in 1977 revealed that the blowing cylinders for this furnace rested on regular stone blocks with holding down bolts (HMS Newsletter 8, 1980). There was no evidence for stone footing blocks at Tintern, and the discovery of a number of beam slots in the blowing house suggests that the cylinders may have rested on timber supports. A similar support system was recorded at the Duddon furnace in Cumbria [20].

The phase 1 cast house at Tintern has parallels in size to those at Craleckan, Bonawe and Sharpley Pool, but the phase 2 cast house (Building J) seems excessively long compared to other examples. It is to be regretted that Building J was not excavated to floor level, as this could have produced evidence for its function and explained its unusual length.

The contemporary Building K is also a puzzle. A longitudinal division of casting floors has been found at Bonawe and Glenkinglass [23] but they do not exhibit the same drop in floor level as existed between Buildings J and K at Tintern.

The best evidence for the total layout of a charcoal ironworks is to be found at Duddon and Newland in Cumbria, and Bonawe and Craleckan in Argyll. The earliest of these furnaces, Duddon, was blown in in 1736, and is thus some 60 years later than Tintern. This difference in date must be borne in mind when using these furnaces as comparative evidence. A feature common to Tintern and all these sites is the solid bridge which supports a bridge house covering the furnace top, and which seems to have been a design used in a number of contemporary coke furnaces as well. The largest structure at Tintern is the charcoal house which is duplicated at the other sites, although Tintern's charcoal house is very small in comparison. This could be explained by the fact that the building at Tintern dates from phase 1, and is thus much earlier. The dimensions recorded in the 1635 survey of the Kings Ironworks in the Forst of Dean are more in accord with Tintern [14]. It must also be remembered that there is documentary evidence for a second charcoal house of unknown size south of the excavated area. Another possible explanation for the disparity in size between Tintern and the Cumbrian and Scottish sites could be that regular charcoal supplies may have been easier to maintain at the former. There are no parallels for the side structures built on to the bridge and charcoal houses at Tintern, although there is a reference in the 1635 inventory mentioned above to a 'shut house for brayse' against the charcoal house at Lydbrook furnace. Could the side structures at Tintern represent separate storage areas for 'brayse' or small charcoal?

The ore stores at Duddon and the other three sites are similar to Tintern in so much as they are smaller than the charcoal houses and have cobbled or paved floors. A paved floor has recently been excavated at the Glenkinglass hematite ore store; the store for the bog iron ore had a turf floor [23]. It is of interest that at all these sites the charcoal houses were unpaved.

One of the features which raises questions at Tintern is the use of stamps. They are recorded in the early 18th century at Clydach, Gwent, for ore crushing, and were being used in the Forest at the end of the century for breaking slag. There seem to be no parallels outside of this area for their application at furnaces and it may be that this is an example of local adoption.

Another problem is the calciner which is recorded on the 1821 inventory, but was not located during excavation. It may have resembled those at Ruardean in the Forest [22], or the one recently excavated at Allensford in Northumberland [21].

With the exception of the phase 2 cast house, Tintern would seem to follow the general constructional and planning details of other 17th and 18th century charcoal blast furnaces. Although it was never a historically important furnace, it is of significance today because it is one of the few places in southern Britain where the total layout of such a site can be seen.

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Special thanks must go to Mr M Taylor, site supervisor and historian, and those members of the excavation team who saw it through to the end.

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Abbreviations

GRO Gwent Record Office

HRO Hereford Record Office

The Norton Ironworks and the casting in 1856, of the first Big Ben bell

David M Tomlin

Abstract

The ironworks site founded in 1856 at Norton near Stockton-on-Tees, County Durham has been continually occupied by industry up to the present day. In its initial year the first Big Ben bell for Westminster, London, was cast, but was so badly damaged during testing that it had to be broken up and re-cast. Dimensions of the two sets of blast furnaces are given together with details of the Player Patent hot blast stove. The ironworks ceased production in 1877, was demolished some decades later and the site occupied by a stone and concrete works.

The casting of a bell in an ironworks has made the author question why this event should occur at Norton (Figure 1) near Stockton-on-Tees in the Cleveland ironmaking district and not in a bell foundry near the site of the erection of the bell in London. Bell metal is a high tin bronze containing up to 25% tin and is not the type of material which would be handled in an ironworks. At Norton near Stockton-on-Tees which was in County Durham, an ironworks had been built in the first half of the 1850s to a plan of three blast furnaces to smelt iron ore from the Cleveland hills with coke and limestone. The large scale exploitation of Cleveland ironstone started in 1850 in the hill above Eston on the south bank of the river Tees. Presumably the owners of Norton ironworks, namely Warner, Lucas and Barrett, reasoned that they should build adjacent to a railway route so that ironstone could be transported in wagons conveniently to the furnace side. Did these partners build next to the route of the 1828 Clarence Railway because coke could be obtained by a direct route from collieries in County Durham? The distance to Norton was shorter by the Clarence Railway than by the first railway, the 1825 Stockton and Darlington. Ironmakers also need quantities of limestone to make a fluid slag and this could be obtained from the Shildon area via the two railways. John Marley[1] reported that:-

> 'two furnaces were erected in 1856 principally for the Swainby and North Yorkshire and Cleveland Railway ironstone'

Does this mean to imply that Norton Ironworks had a contract with the North Yorkshire and Cleveland Railway to supply them with ironstone? On the other hand did Warner and partners contract with the Swainby mine to be supplied with ironstone over the rails of the North Yorkshire and Cleveland Railway? Chapman[2] ,in a recent booklet, says that the Swainby mine was operated in the 1856-1865 period for a Stockton group of blast furnace owners, named Holdsworth, Bennington, and Byers. As Norton Ironworks never owned an ironstone mine of its own, unlike other companies in the Cleveland area, they must have bought their raw material on the open market or by short term contracts.

The early days of operation did not run completely smoothly for Richmond[3] reports a fatal accident occurring on 1st August, 1856:-

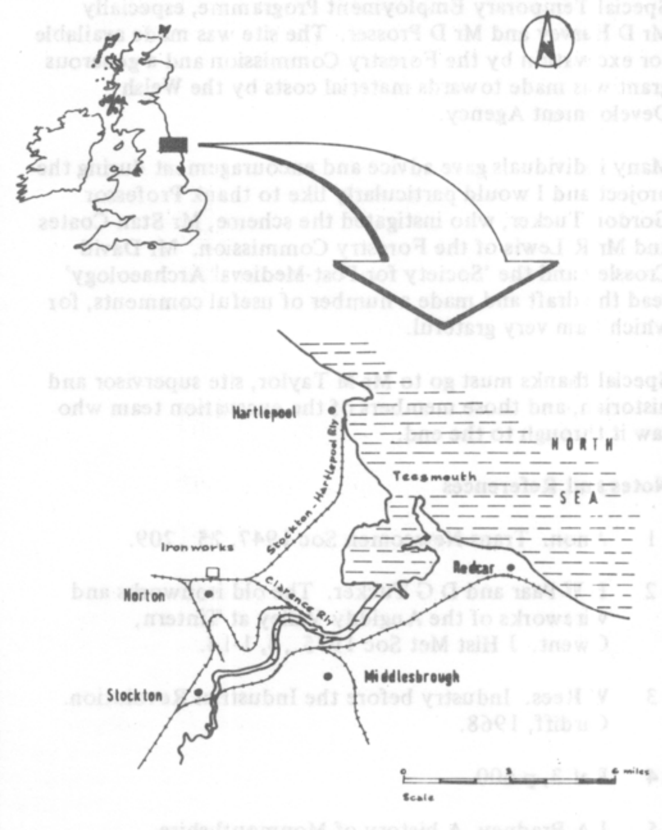

Fig 1 Location map of Norton, north of Stockton-on-Tees in North East England

> 'Alfred Benson, joiner,killed at the Norton Blast Furnaces by becoming entangled with the machinery in the engine room'.

This statement suggests that a joiner was finishing the construction of the steam engine house when the machinery was running, in the very early weeks of operation of this works.

Norton and the First Big Ben Bell

An event of national interest occurred at the works on 6th August, 1856 when a great bell for the new Palace of Westminster was cast. This was brought to the attention of the Victorian people by the Illustrated London News[4] on 23rd August with an engraving of the foundry scene and a description: (See Fig 2)

> **'Casting the Great Bell for the New Palace of Westminster.**
>
> The vicinity of the picturesque village of Norton, near Stockton-on-Tees was on the morning of the 6th instant, the scene of an event of considerable interest – the casting of the Great Bell for the clock-tower of the new Palace at Westminster which was successfully accomplished at Messrs Warner, Lucas and Barretts

furnaces, by Messrs Warner and Sons of the Crescent Foundry, Jewin Street, London, well-known as the patentees of an improved method of casting church bells.

The preparation of the mould – of the method of constructing which our small engraving is a representation – had occupied six weeks, and two reverberatory furnaces, capable of melting ten tons of metal each, had been built expressly for the purpose of casting this monster bell.

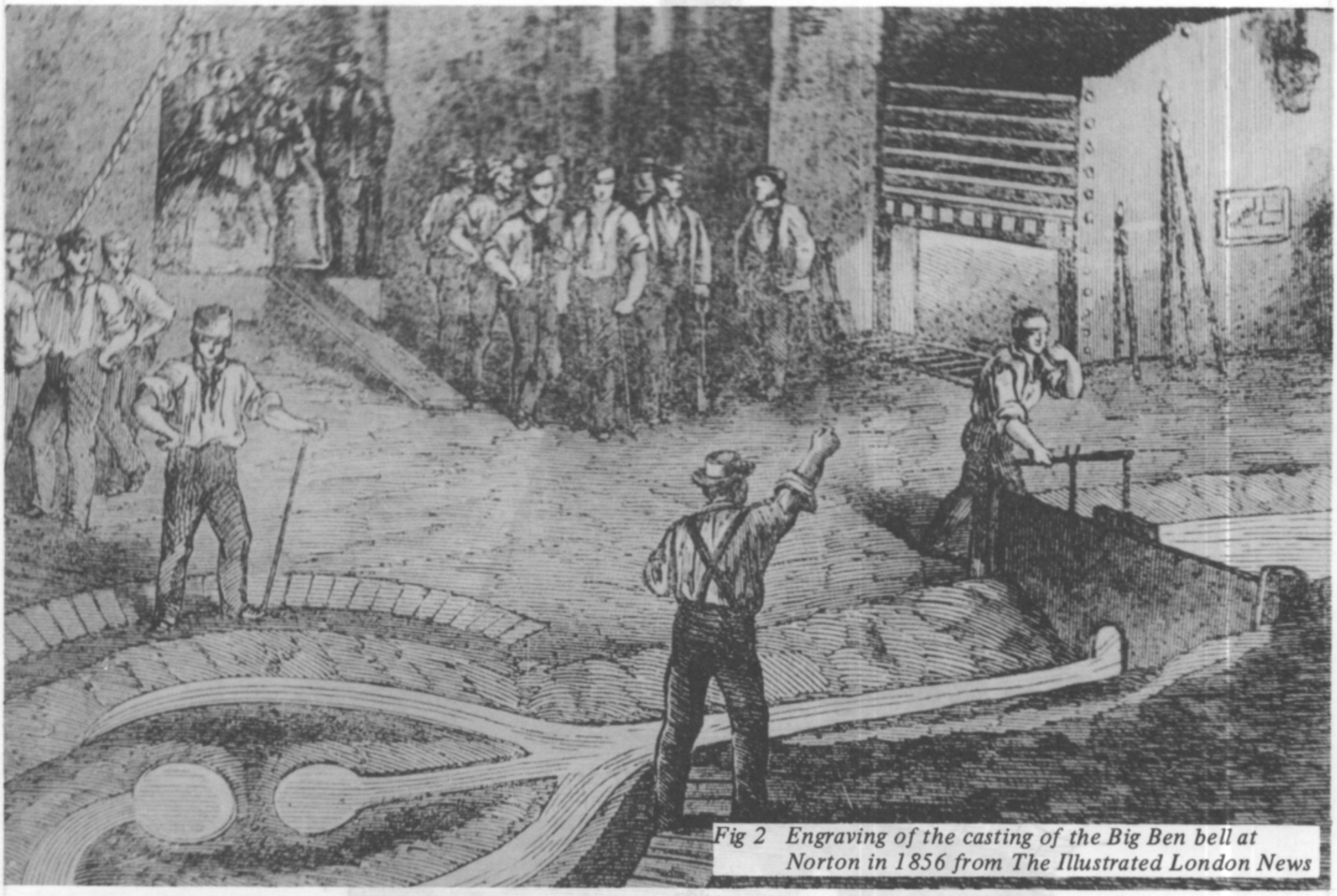
Fig 2 Engraving of the casting of the Big Ben bell at Norton in 1856 from The Illustrated London News

The lower portion of our explanatory engraving (Fig 3) represents a section of the brick vault or pit in which the bell was cast and shows the method of strickling the core or centre of the mould which is to produce the concavity of the bell. On the floor is a circular iron plate of the requisite circumference, on which a mass of sand and loam is brought to the required shape by means of a piece of wood cut to the required section and moved in a regular circular direction by means of its connection with a pivot running perpendicular through the centre.

The upper portion represents an iron cap of the same circumference as the iron plate at the bottom of the pit. The interior of this is coated with sand and shaped to the required section in a precisely similar manner as that adopted for the core before described, though of course inversely, as in this case it is done from the interior. The two being complete, the cap is let down over the core and riveted to the iron plate at the bottom – the space between the core and the lining of the cap forming the mould into which the metal is to run. The remaining space in the pit is then filled with sand, pigs of iron carefully rammed down, and the necessary channels for the metal to run from the furnace into the mould having been made, the arrangements are then complete.

We now return to the operation of casting, of which our large Engraving is a representation (Fig 2). The whole of the night previous was a scene of busy industry and early in the morning the furnace seen to the right in the background having attained the requisite heat, their doors were opened, and the operation of charging, or putting in the metal, commenced, occupying about one hour, and in less than two hours and a half the whole of the metal (18 tons) was in a state of perfect fusion. On the signal being given the furnace was tapped, and the metal flowed from them in two channels into a pool prepared to hold it, before being admitted into the bell mould. The shutter, or gate, was then lifted, and the metal allowed to flow, which in five minutes completed the casting of the bell, the successful termination of which delighted all present, who cordially joined the workmen in three hearty cheers.'

As the bell was such a large casting it was some days before it cooled and was removed from the casting pit, so the next Illustrated London News[5] report appeared on 13th September. The account says the bell was raised from the pit on 22nd August, the diameter 9 feet 5½ inches, the height outside 7 feet 10½ inches, inside 6 feet 8 inches. The bell was of 'E' natural note. An inscription just above the

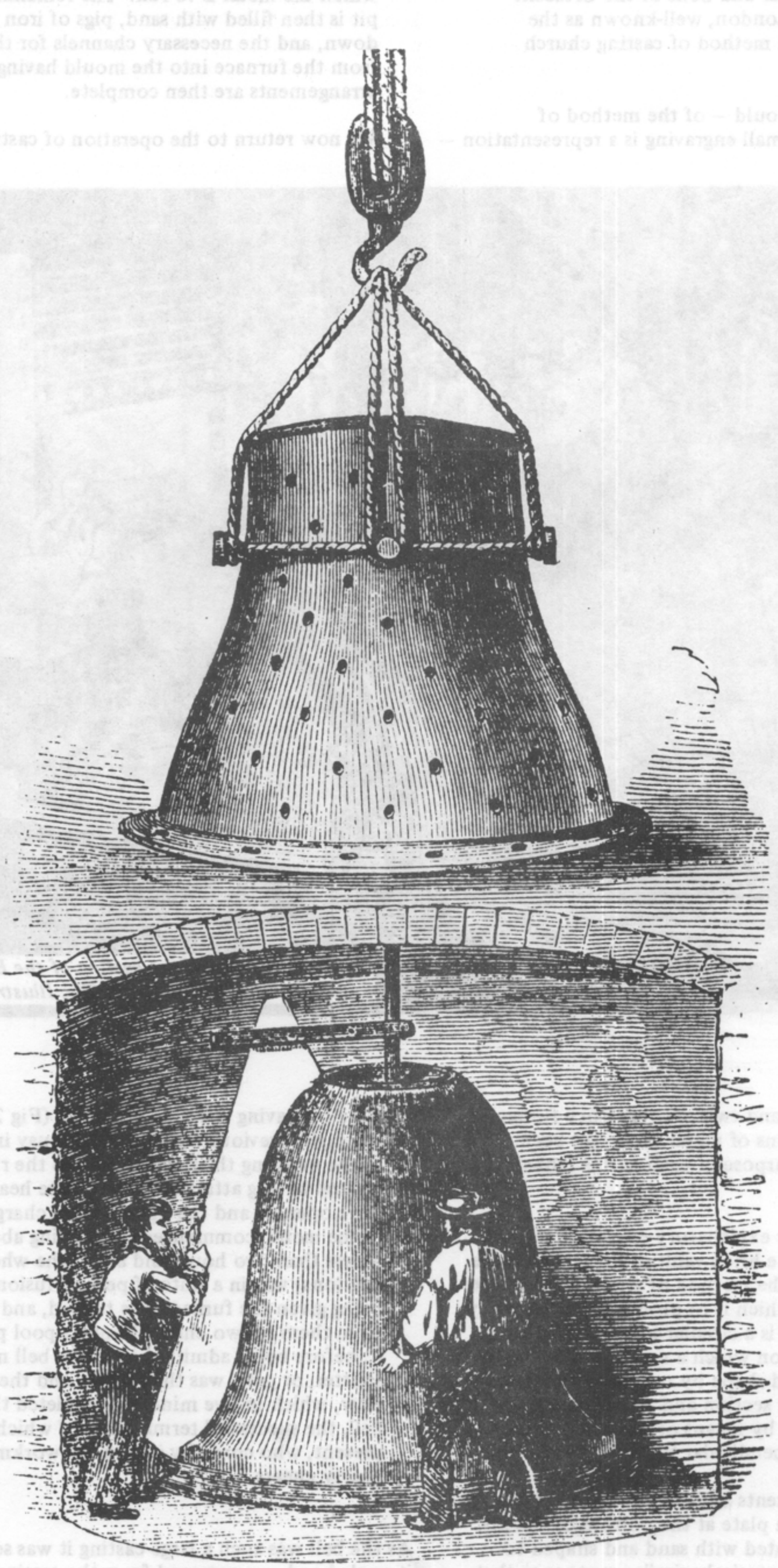

Fig 3 Method of making the bell mould.

sound bow read:

> 'Cast in the 20th year of the reign of her Majesty Queen Victoria and in the year of our Lord 1856, from the design of Edmund Beckett Denison Q.C., Sir Benjamin Hall, Baronet, M.P. Chief Commissioner of Works.'

On the middle of the bell were the Royal arms. The top inscription read:

> 'John Warner & Sons, Crescent Foundry, Cripplegate, London'.

From this information it appears that John Warner or his son originated in London, and must have seen an opportunity in north east England with the rapid exploitation of the Cleveland ironstone from 1850. Warner must have found the other partners, Lucas and Barrett, to establish an ironworks at Norton.

The bell was stated to weigh 15 tons 18 cwt 1 qr 22 lb, having a thickness of 9 3/8 inches at the soundbow and 3 1/8 inches in the upper part. The great bell was sent down from Norton to West Hartlepool by railway on a Sunday, being too wide for any train meeting it to pass. The composition was 7 of tin to 22 of copper, melted twice over, to secure a perfect alloy. That proportion was adopted after trying experimental bells of various proportions and the shape which was fuller at the soundbow than usual, was determined in the same way. That metal composition of 24% tin and 76% copper puts it in a tin bronze classification according to a technical dictionary[6]. This metal composition was unsuitable for a bell according to a statement from a twentieth century foundryman from the Whitechapel bell foundry in London.[7]

> 'He (Big Ben) contains four percent more tin than we would have used in this foundry if we had made the metal ourselves.'

A drawing in the 1st November Illustrated London News[8] shows the bell being drawn by sixteen horses on a low truck into the Palace Yard. In the afternoon the bell was lifted into a frame at the foot of the Clock Tower, then tested twice and pronounced free from crack or flaw. The bell was to be called 'Big Ben' in honour of Sir Benjamin Hall, the President of the Board of Works, during whose tenure of office it was cast.

Mr Denison, designer, Mr Dent, the maker of the bell and Mr Quarm, the clerk of the new Palace works were reported[9] as testing the bell with an approximately half ton hammer.

At some stage of testing the bell was badly damaged and as a result had to be broken up for re-casting. An account[10] says that on 17th February 1858 the bell was laid on its side and a 24 cwt iron ball dropped on the bell to break it into fragments, then carted away to Mears foundry at Whitechapel in London. The bell was recast[11] in April 1858 although the mould had been started in December 1857. The metal was melted in three furnaces holding together nearly 18 tons, sixteen tons from the old bell and the rest new metal. It took about 20 hours to melt the large pieces and Mears used wood fuel, not coal. The report said that preheating the mould by blowing in hot air was performed for the first time in bell founding. This preheating was carried out for the whole of the day before casting. Mr Denison wished to have it done with the first bell but Warner thought it unnecessary but it was made one of the conditions of the contract. It took 20 minutes to fill the mould by regulation of the flow of the molten metal.

It is perhaps strange that the second casting made in London was called 'Big Ben' and not a different name as was suggested in 1858. Then the Illustrated London News[10] said the bell could be called 'Big John' after the new Chief Commissioner of Works.

Ingram [12] in 1954 says that when Mears accepted the contract, it was stipulated that the bell was not to be struck with a hammer heavier than four hundredweight. The clock struck perfectly for two months, and then it was discovered that the bell was cracked. Lord Grimthorpe said that this was not caused by the hammer but had been there since the bell was cast and that Mears had concealed it with cement and paint, but it was found that the hammer weighed seven hundredweight and not four. For three years the hours were struck on the fourth quarter bell and then Big Ben was turned round slightly and a four hundredweight clapper fitted. Though cracked it has rung ever since.

Over the years various authors have made errors when describing 'Big Ben' which is known world wide due to the BBC broadcasting its ringing sound as a time signal. Morton[7] is mistaken when he says 'the first Big Ben was cast in Yorkshire'. At the time of the casting right up until 1968 Norton was in County Durham. Then a new area called Teesside was created from the Borough of Middlesbrough and part of north Yorkshire and part of south Durham. Another new boundary of even greater area occurred in 1974 with the formation of Cleveland.

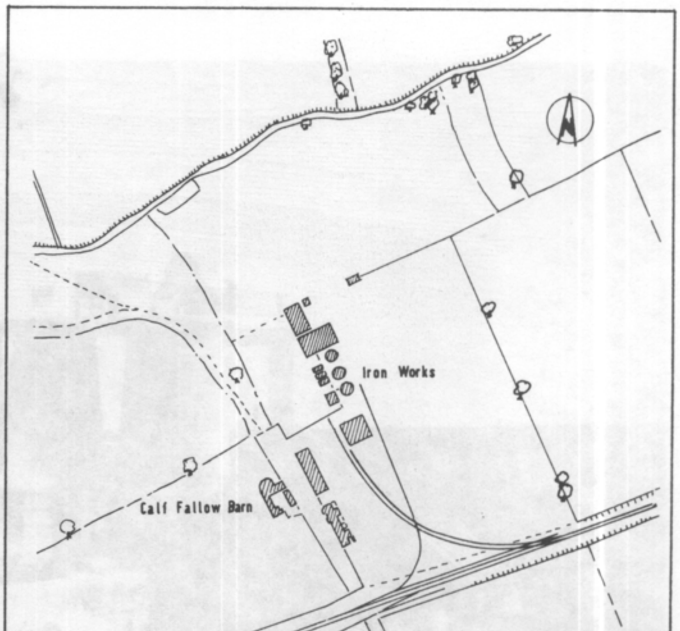

Fig 4 Norton Ironworks in 1856 showing plan with three blast furnaces, based on OS map.

The Blast Furnaces of the Norton Ironworks

Back in the last century, after the casting of the bell, the blast furnaces situated as shown in Fig 4 were producing iron. The dimensions of the three furnaces can be obtained from a review[13], they were 50 feet high, 15 feet in diameter with a 6 foot hearth, each having a volume of 6,000 cubic feet. Improvements in the technology of ironmaking were made at Norton in parallel with many ideas in the Cleveland District as is described in the following extract[14]:

> 'In 1862, Mr Barrett, of Norton near Stockton-on-Tees, filled his ordinary fore-hearth completely up with fire-clay, and worked his furnaces with the front quite closed up, a hole being made through the fire-clay for the slag; and as the hole burnt away, fresh fire-clay was rammed in. This plan worked so well that when he (Mr Barrett) erected his large furnaces in 1866 he built them upon the same system, but making his well with two tapping holes and two slagging holes on opposite sides of the hearth arranged in the same way as in 'Birch's' and in 'Alger's' furnaces, except that the hearth was circular. These furnaces continue to work well, and were for some time the only ones in the Cleveland district, perhaps in England, which worked with a closed front.'

This filling in of the fore-hearth reduced the possibility of catastrophic break outs of the molten iron and slag which happened in many other ironmaking districts, often killing furnacemen as a result. Today this appears to be a very small step forward, but it was quite revolutionary in its day, and enabled ironmasters in the Cleveland district to build taller bodies to the blast furnaces and increase output. Cleveland in the 1870s was leading the United Kingdom with the highest tonnage of iron made in any single region as can be seen from the following data[15]

1872	
Yorkshire, North Riding	1,122,114 tons (Cleveland)
Scotland	1,090,000 tons
Wales	1,057,315 tons

At Norton Ironworks, the management were also concerned with the efficient use of fuel for Mr Player patented a hot blast stove with a separate combustion chamber. The first reference that the present author found to this information was given by Richmond[16]

> 'An ingenious mode of utilizing the waste gases from blast furnaces has been invented by Mr John Player of Norton which consists essentially of drawing them into a hot-blast stove by means of a steam jet, and then consuming them.'

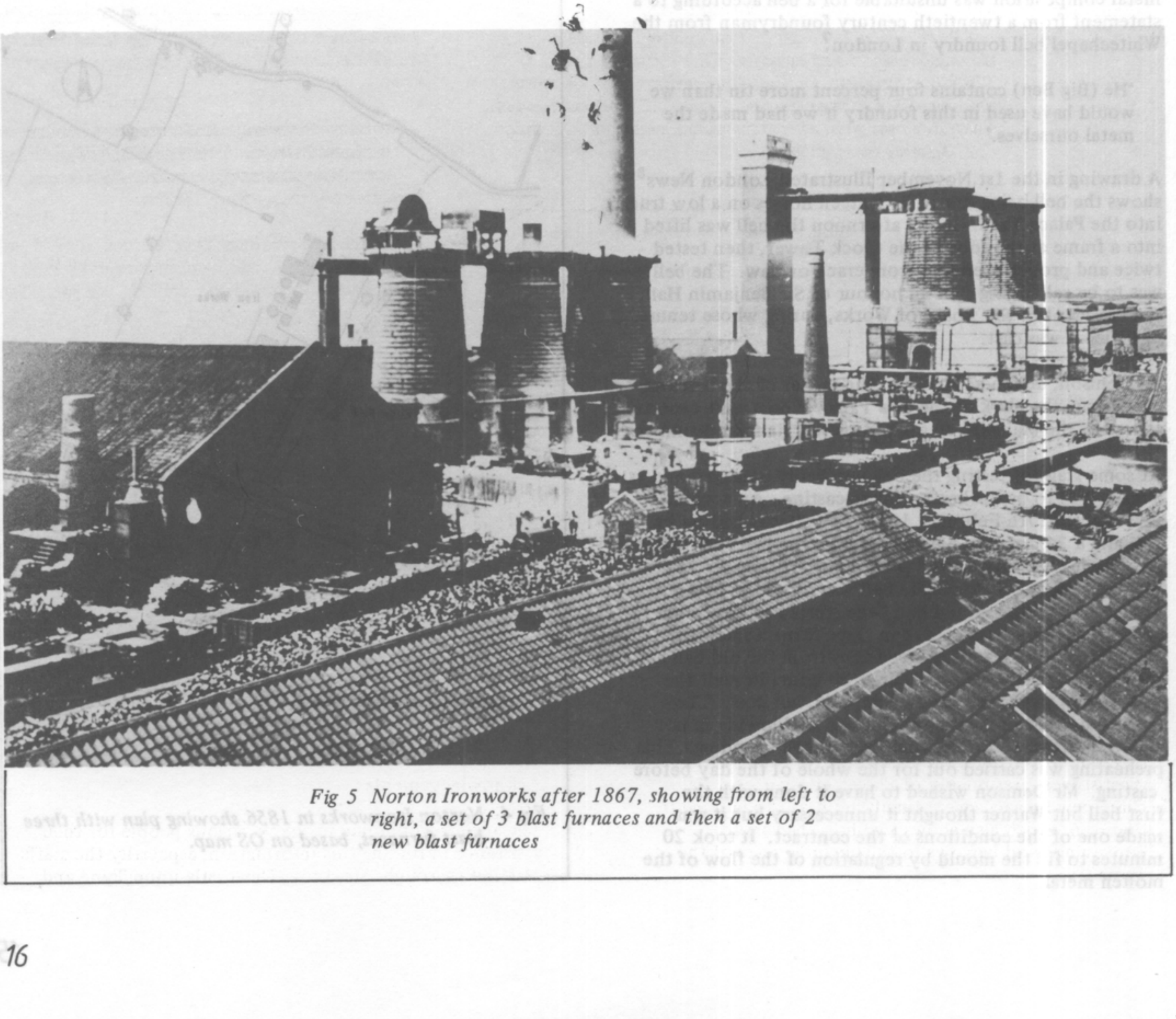

Fig 5 Norton Ironworks after 1867, showing from left to right, a set of 3 blast furnaces and then a set of 2 new blast furnaces

This Victorian language hides the facts that can be found more clearly in **Engineering**[17]. In the engraving was shown a pair of heating stoves capable of heating about 5000 cubic feet of air per minute to a temperature of 1000° to 1200°F. Each stove contained 36 cast iron pipes, 12 inches in diameter by nearly 14 feet high, which had about 3400 square feet of heating area. At the time of this report in 1866, eighty stoves of this design were being used in the United Kingdom, with examples at Carnforth Hematite Ironworks, Whitwell and Co at Thornaby who had six in operation and Consett Ironworks who had four.

The development of the hot blast stove has been covered in **Historical Metallurgy**[18] from the first patent of Nielson in 1828 which used iron pipes through to the Cowper stove using a brick packing. E A Cowper patented in 1857 a stove based on the Siemens regenerative principle which was quickly taken up by Cochrane & Co at their Ormesby Ironworks near Middlesbrough. This type of stove has a honeycomb packing of firebricks instead of cast iron pipes in its core. It appears that Player's design was the last development of pipe stoves in the Cleveland district before checkerbrick finally replaced packing in stoves for the blast furnace. Player's design was used in the North East for a few years in the late 1860s and preceded by about three years Thomas Whitwell's patent of 1868. The two types of stove were compared by Whitwell[19] using data from Consett and Thornaby.

> 'Both furnaces are burdened with the same mixture but one has five cast-iron stoves, on Player's patent, erected three years ago, containing 175 tons of pipes and having 6,500 square feet of heating surface, the average heat of blast being by Siemens pyrometer 900°. In this case, we find the consumption of coke, per ton of grey forge pig iron, to be 22½ cwt compared with that supplied with the writer's new stoves, which is 17½ cwt over a period'.

	Height Feet	Bosh Dia Feet	Hearth Ft Ins	Make in Week Tons	Temp. °F	Coke Cwt
Consett Furnace Fire-Brick Stoves	55	20	7 - 5	430	1,400	17½
Consett Furnace Cast-Iron Stoves	55	20	7 - 5	430	900	22½
Thornaby Furnace Cast-Iron Stoves	60	20	7 - 6	390	1,050	21½

All on a mixture of 2/3 Cleveland and 1/3 Hematite iron ore

A new set of taller blast furnaces were built at Norton in the 1866-67 period, and their dimensions given in a review of Cleveland[13] states they were 85 feet high, 25 feet bosh and 7 feet 6 inches at the hearth, giving a volume of 26,000 cubic feet. The earliest photograph (Figure 5) shows two furnaces on the right with the old set on the left. A taller hoist tower can also be seen. The scene looks very busy with a tank engine hauling wagons in the left foreground. Around the base of the new furnaces are hot blast stoves, presumably of Player's design. A total of three new furnaces were finally built as can be seen in Figure 6, which also shows two hoist towers for conveying hand barrows to the charging level of the furnace.

The new furnaces had a large volume at 26,000 cubic feet compared to others in Cleveland. Mr I Lowthian Bell was speaking and writing books about the metallurgy of iron-making at that time and at his own Clarence Ironworks, just a few miles away, his new 1866 furnace was only 80 feet high with a small volume of 11,500 cubic feet as it was slim at 17 feet diameter. Another large furnace was at Ormesby Ironworks in 1867, being 76 feet high, fat at 23 feet diameter giving a volume of 20,624 cubic feet[13]. So it appears that Norton was giving the lead to Cleveland in 1867, having the furnace with the largest volume.

The statistical data about blast furnaces published by the Iron and Steel Institute appear to contain an error. A list published in 1871[20] says there are only two furnaces built and two in blast at Norton. At that time there were either five or six furnaces built from the evidence in the photographs (Figures 5, 6, 8) North[21] in a recent book has a very similar table dated 1871 listing three furnaces built and three in blast. It appears that the original source is the same, as the furnaces are listed in the same order and Norton is followed by an entry 'Norwegian Titanic Iron Company' which the current author cannot identify, although it is listed under Stockton-on-Tees. So errors appear in data tables published both in 1871 and recently in 1975 .

Late in July 1877 the Norton Ironworks stopped production due to the economic depression in the iron industry[22]. Previously on 14th July the men received two weeks notice in a hand written letter signed by William Barrett, one of which has luckily survived in the Local History collection of Stockton Library[23]. The newspaper report[22] also says that:-

> 'part of the works embracing one furnace and the chair manufactory has been standing [idle] for some time and now the remaining furnaces which employed about 200 men are being damped down.'

This author's interpretation of the word 'chair' is that they were probably casting rail chairs for railways. The works went into liquidation in the 1878-79 period although it was listed in 1861[21] as having six blast furnaces standing. William Barrett was listed up until 1883[25] as being a member of the Iron and Steel Institute and his address is given as Norton Ironworks. After 1884[26] his name does not appear as a member of the Institute.

The new blast furnaces were demolished in 1898[27] from the date given on the back of the original mounted photograph (Figure 8). On the site of the ironworks was built the Stockton Stone and Concrete Works (Fig 9) and according to a newspaper report[28] it was a Mr J L Wilson who started this in 1904. Later in 1933 Mr Eric Wilson, the son, became the managing director of the company until it was purchased by Marshalls of Halifax in 1967. Mr Wilson, junior, served on the National Joint Industrial Council for the concrete industry for sixteen years from 1933.

Today Marshalls (Teesside) Ltd[29] still make concrete blocks at Norton on the site of the casting of the first Big Ben bell, on the north side of the railway at the end of Station Road.

Acknowledgements

The author would like to thank various people for their assistance in finding this information, especially the staffs of Middlesbrough, Stockton, Newcastle upon Tyne and

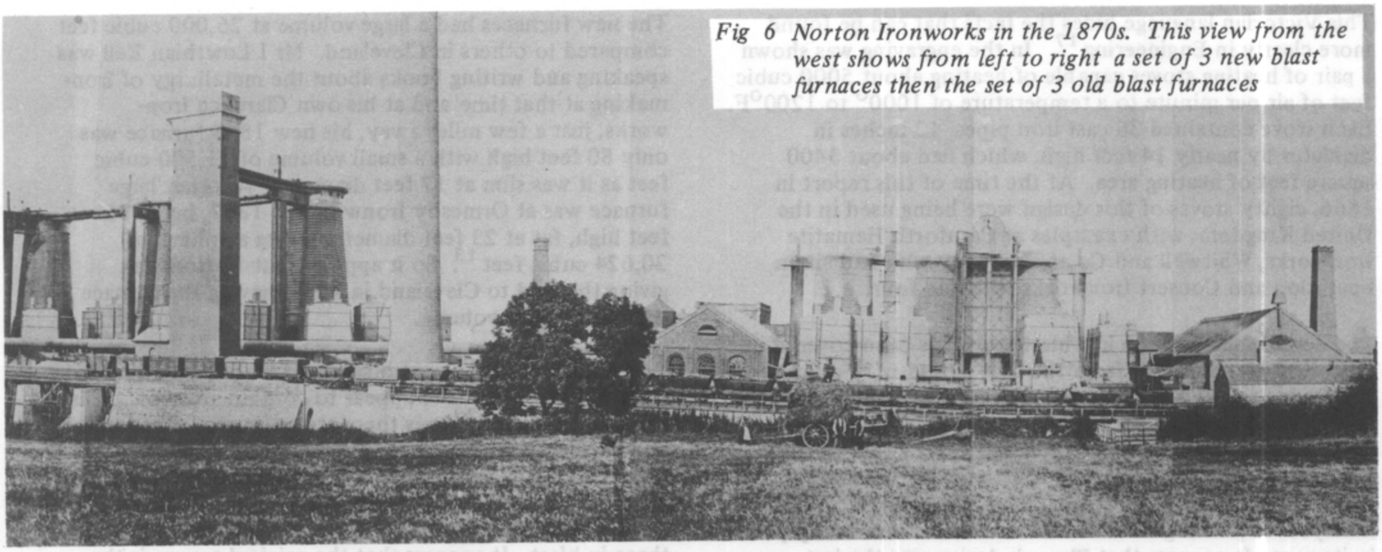

Fig 6 Norton Ironworks in the 1870s. This view from the west shows from left to right a set of 3 new blast furnaces then the set of 3 old blast furnaces

Darlington Libraries. Also the staff of Stockton-on-Tees Museum and Mr E Parker, Mr B Deakin and Miss G Boxall.

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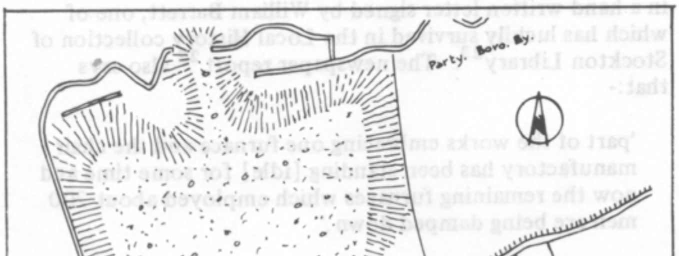

Fig 7 Norton Ironworks from an 1899 OS map. This plan shows only 3 new blast furnaces, with the old furnaces missing presumably demolished

20 JISI, 1871, 2, iii.

21 G A North, Teesside's Economic Heritage, 1975, Middlesbrough, County Council of Cleveland.

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23 Letter of Notice, 14th July, 1877, signed by William Barrett, Local History Collection, Stockton Reference Library.

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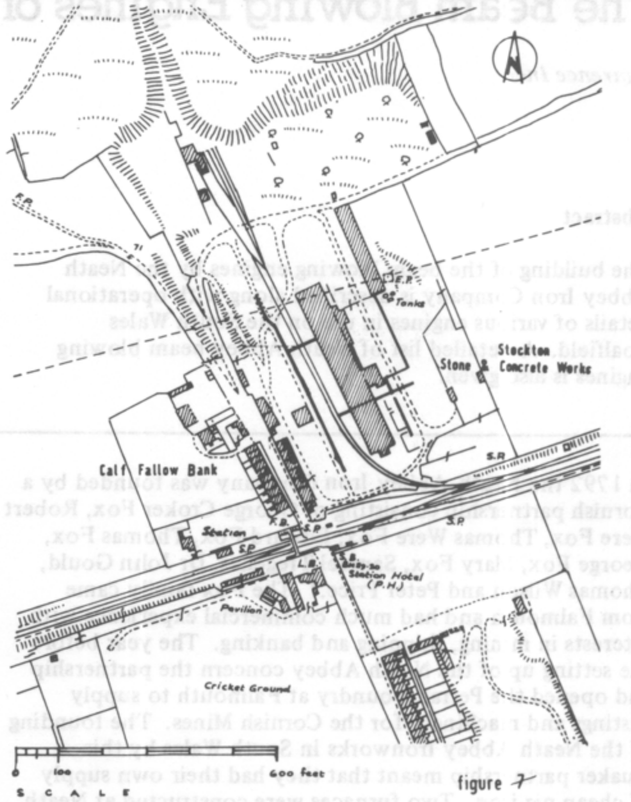

Fig 9 Stockton Stone and Concrete Works in 1939 on the site of the ironworks

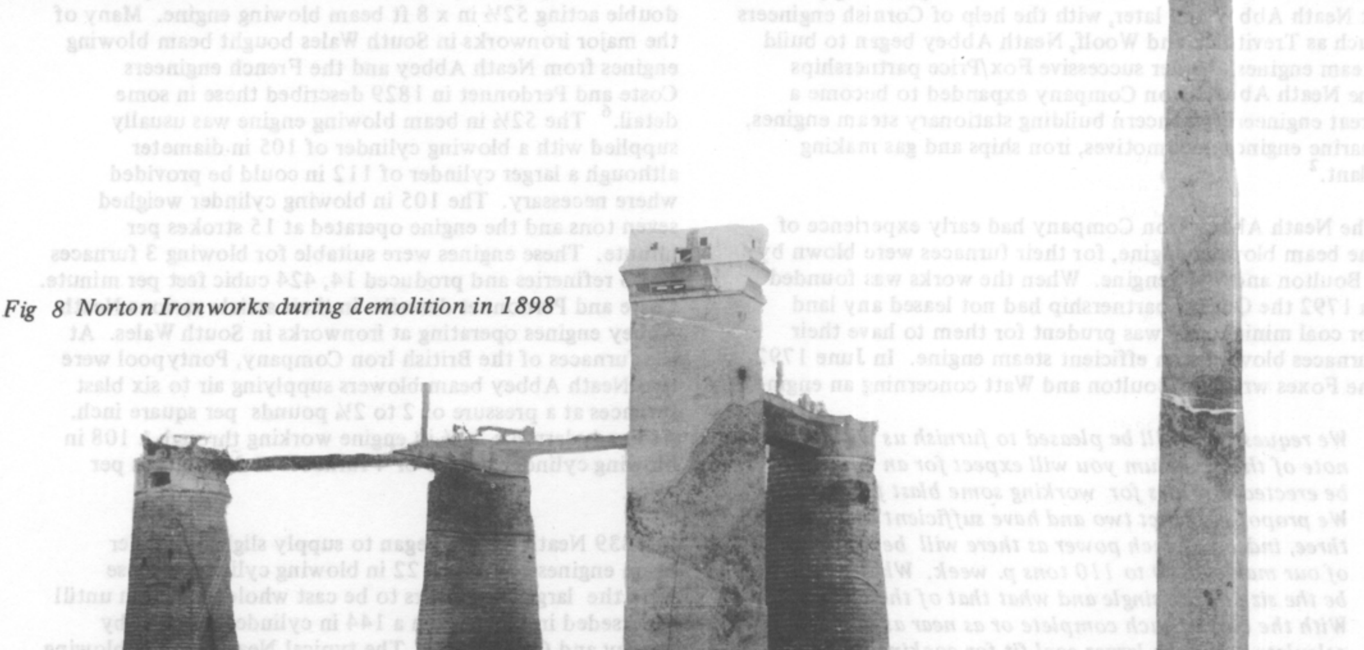

Fig 8 Norton Ironworks during demolition in 1898

The Beam Blowing Engines of the Neath Abbey Iron Company

Laurence Ince

Abstract

The building of the beam blowing engines by the Neath Abbey Iron Company is described along with operational details of various engines in use on the South Wales Coalfield. A detailed list of Neath Abbey beam blowing engines is also given.

In 1792 the Neath Abbey Iron Company was founded by a Cornish partnership consisting of George Croker Fox, Robert Were Fox, Thomas Were Fox, Edward Fox, Thomas Fox, George Fox, Mary Fox, Samuel Tregelles, Dr John Gould, Thomas Wilson and Peter Price.[1] The Fox family came from Falmouth and had much commercial experience with interests in mining, shipping and banking. The year before the setting up of the Neath Abbey concern the partnership had opened the Perran Foundry at Falmouth to supply castings and machinery for the Cornish Mines. The founding of the Neath Abbey Ironworks in South Wales by this Quaker partnership meant that they had their own supply of cheap pig iron. Two furnaces were constructed at Neath Abbey and Peter Price, an experienced ironworker acted as manager from 1800 to 1818.

It was soon realised by the partnership that it would be more efficient to produce some of their engineering products at Neath Abbey and later, with the help of Cornish engineers such as Trevithick and Woolf, Neath Abbey began to build steam engines. Under successive Fox/Price partnerships the Neath Abbey Iron Company expanded to become a great engineering concern building stationary steam engines, marine engines, locomotives, iron ships and gas making plant.[2]

The Neath Abbey Iron Company had early experience of the beam blowing engine, for their furnaces were blown by a Boulton and Watt engine. When the works was founded in 1792 the Quaker partnership had not leased any land for coal mining so it was prudent for them to have their furnaces blown by an efficient steam engine. In June 1792 the Foxes wrote to Boulton and Watt concerning an engine:

> *We request you will be pleased to furnish us with a note of the premium you will expect for an engine to be erected in Wales for working some blast furnaces. We propose to erect two and have sufficient blast for three, indeed of such power as there will be no doubt of our making 100 to 110 tons p. week. What would be the size of the single and what that of the double? With the cost of each complete or as near as you can calculate – for the larger coal fit for coaking we shall most likely pay upwards of 3/- p. ton, but coals for the engine ought to be reckoned at a much less rate.*[3]

The Birmingham partnership replied in September informing the Quaker partners that the engine required would be the most powerful blowing engine ever erected and that:

> *We cannot help recommending a double engine for this particular purpose in preference to a single one as the blast becomes more uniform and requires less of what is commonly called Regulating Belly. Such an engine when blowing the 3 furnaces will consume about 5 bushels of good coal an hour whereas the common engines we have seen applied to blowing, burn 4 times that quantity in proportion to the work done. As to the Blowing Cylinder and Regulating Belly, we will undertake to be your engineers in them and make such drawings for the founders, the smiths etc, as may be necessary without charging anything for the same and perhaps our knowledge and experience in that part of the machinery may be found to be of some importance.*[4]

After some further correspondence the engine was ordered and the furnaces were soon being blown by the engine which was double acting with a cylinder cast at Coalbrookdale of 40 inches diameter and eight feet long. The engine being able:

> *to work a blowing cylinder of 70 inches diameter and eight feet long in the stroke, both upwards and downwards where the piston of the said blowing cylinder is not charged with a resistance greater than 2 pounds and ¾ on every square inch of the said piston.*[5]

The position of the Neath Abbey Ironworks on the South Wales Coalfield meant that it was ideally placed to supply machinery to the developing coal and iron industries. One of the most popular products built at Neath Abbey was a double acting 52½ in x 8 ft beam blowing engine. Many of the major ironworks in South Wales bought beam blowing engines from Neath Abbey and the French engineers Coste and Perdonnet in 1829 described these in some detail.[6] The 52½ in beam blowing engine was usually supplied with a blowing cylinder of 105 in diameter although a larger cylinder of 112 in could be provided where necessary. The 105 in blowing cylinder weighed seven tons and the engine operated at 15 strokes per minute. These engines were suitable for blowing 3 furnaces and 3 refineries and produced 14, 424 cubic feet per minute. Coste and Perdonnet describe in their article various Neath Abbey engines operating at ironworks in South Wales. At the furnaces of the British Iron Company, Pontypool were two Neath Abbey beam blowers supplying air to six blast furnaces at a pressure of 2 to 2¼ pounds per square inch. At Pendydarren a 52½ in engine working through a 108 in blowing cylinder blew 3 or 4 furnaces at 2½ pounds per sq in.

In 1839 Neath Abbey began to supply slightly smaller beam engines but with 122 in blowing cylinders, these were the largest cylinders to be cast whole in Britain untill superseded in 1843 when a 144 in cylinder was cast by Harvey and Co of Hayle. The typical Neath Abbey blowing engine was constructed with an upswept beam at the steam end which was connected to a large flywheel. This design was employed by the Neath Abbey Iron Company right up to 1872 when they built their last beam blowing engine which was supplied to the Cefn Ironworks at Pyle, Glamorgan.

When the Neath Abbey Ironworks closed in 1886 it had produced no less than 30 large blowing engines for the British iron industry and had also exported several examples of these engines. The closure of the works was directly related to the decline of the South Wales iron and copper industries. However, the Neath Abbey Ironworks had been a major supplier of engines and plant to the British iron industry during the nineteenth century and had made a major contribution to the development of the industries of the South Wales Coalfield.

Beam Blowing Engines Built by the Neath Abbey Iron Company[7]

Date	Customer	Details
1817	Wayne, Williams & Co, Gadlys Ironworks, Aberdare	33 in
1819	Blaenavon Ironworks	52½ in
1819	Hill & Sons, Plymouth Ironworks, Merthyr Tydfil	52½ in
1819	Penydarren Iron Company, Merthyr Tydfil	52½ in
1820	Cyfarthfa Ironworks, Merthyr Tydfil	52½ in
1820	Hirwaun Ironworks	52½ in
1823	Guant & Co, Pembrey	30 in
1826	British Iron Co, Pontypool	Two 52½ in
1827	Wayne, Williams & Co, Gadlys Ironworks, Aberdare	34 in
1827-30	Aveyron Mining Co, France	Three 45 in
1828	Leigh and George, Pontypool	52½ in
1836	Nantyglo Ironworks	60 in
1837	Golynos Iron Company	52½ in
1837	Penydarren Iron Company	38½ in
1838	Dowlais Iron Company	40 in
1838	Cambrian Iron and Spelter Co	52½ in
1839	Hirwaun Ironworks	52½ in
1839	Gwendraeth Anthracite & Iron Co	24 in
1839	Victoria Ironworks, Ebbw Vale[8]	Engine with 122 in blowing cylinder

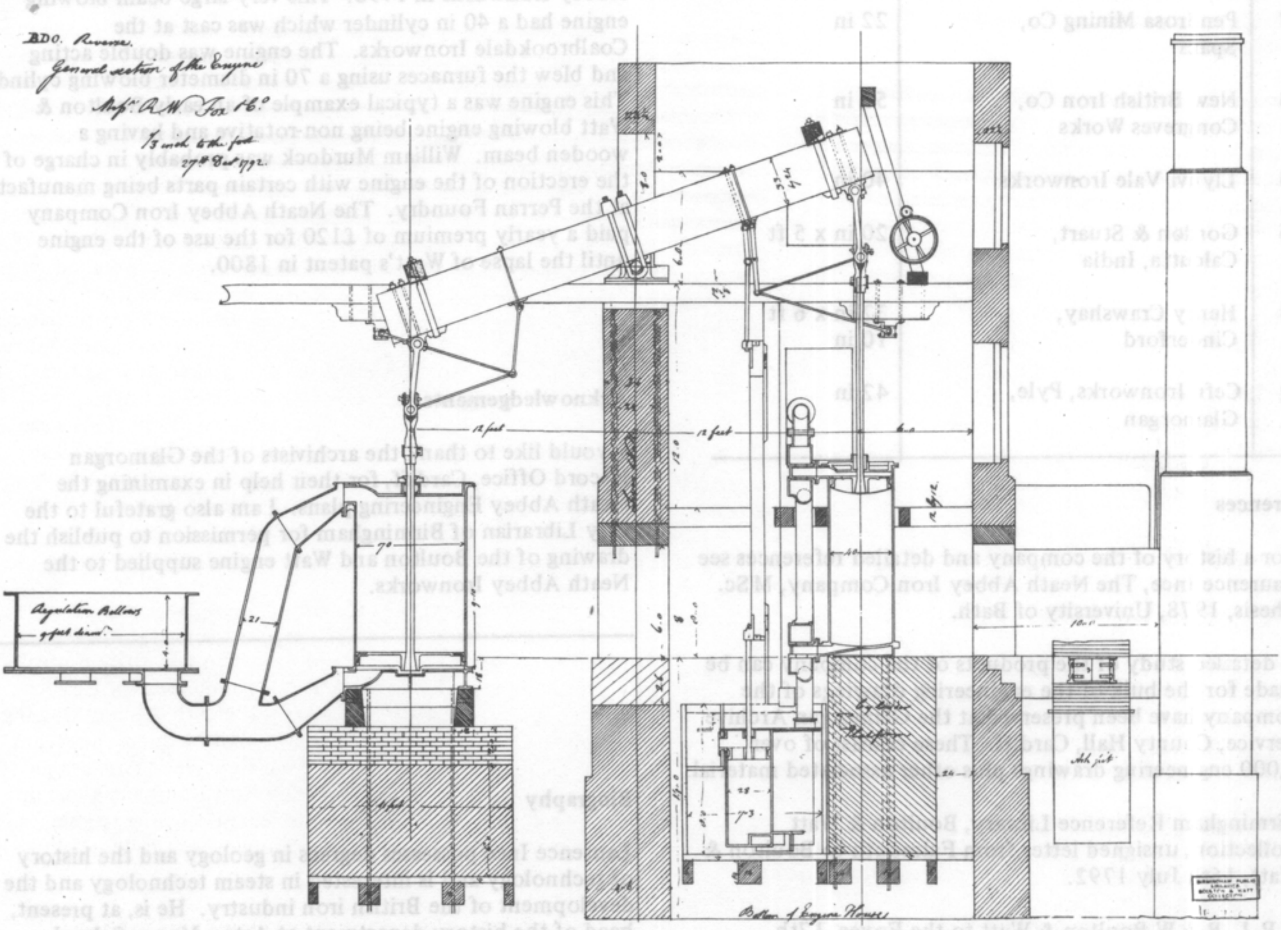

Plate One. Boulton and Watt 40" Blowing Engine built 1793

Date	Customer	Details
1839	Tredegar Iron Co	42 in, with 122 in blowing cylinder
1839	Rhymney Iron Co	Two 52½ in
1839	Sirhowy Iron Co	38 in
1840	Blaenavon Ironworks	52½ in
1840	Clydach Ironworks	52½ in
1840	Cyfarthfa Ironworks	52½ in
1845	Ystalyfera Ironworks	52½ in
1845	Crawshay Bailey, Nantyglo Ironworks	44 in x 9 ft with 122 in blowing cylinder
1846	Trimsaron	32½ in
1847	F Hugh & Co, Spain	24 in x 7 ft
1847	F L Riant and Langlois, Aubin, France	Two 45 in x 8 ft
1847	F Ade Elorza, Spain	22 in
1847	Pendrosa Mining Co, Spain	22 in
1853	New British Iron Co, Congreves Works	52 in
1855	Llynvi Vale Ironworks	40 in
1856	Gordon & Stuart, Calcutta, India	20 in x 5 ft
1865	Henry Crawshay, Cinderford	32 in x 6 ft 10 in
1872	Cefn Ironworks, Pyle, Glamorgan	42 in

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1 For a history of the company and detailed references see Laurence Ince, The Neath Abbey Iron Company, M Sc. Thesis, 1978, University of Bath.

2 A detailed study of the products of the company can be made for the bulk of the engineering drawings of the company have been preserved at the Glamorgan Archive Service, County Hall, Cardiff. These consist of over 2,000 engineering drawings plus other associated material.

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7 This list has been compiled from the engineering drawings of the Neath Abbey Iron Company. Some of these engines are represented by tens of drawings of component parts whilst others are represented by a single drawing. After many years of building engines, the works was able to build a common design of engine without producing a new drawing, or perhaps just one or two for a particular modification. Indeed many of the engines are only represented by a note on a drawing for another engine. It is often difficult to determine the type of an engine which is represented in the collection by a drawing of a minor detail and it could be that this list is an underestimate of beam blowing engines produced by the company.

8 D B Barton, The Cornish Beam Engine, Truro, 1969, p 265.

Plate One (Overleaf)

The Boulton & Watt blowing engine built at the Neath Abbey Ironworks in 1793. This very large beam blowing engine had a 40 in cylinder which was cast at the Coalbrookdale Ironworks. The engine was double acting and blew the furnaces using a 70 in diameter blowing cylinder. This engine was a typical example of an early Boulton & Watt blowing engine being non-rotative and having a wooden beam. William Murdock was probably in charge of the erection of the engine with certain parts being manufactured at the Perran Foundry. The Neath Abbey Iron Company paid a yearly premium of £120 for the use of the engine until the lapse of Watt's patent in 1800.

Acknowledgements

I would like to thank the archivists of the Glamorgan Record Office, Cardiff, for their help in examining the Neath Abbey Engineering plans. I am also grateful to the City Librarian of Birmingham for permission to publish the drawing of the Boulton and Watt engine supplied to the Neath Abbey Ironworks.

Biography

Laurence Ince possesses degrees in geology and the history of technology and is interested in steam technology and the development of the British iron industry. He is, at present, head of the history department at Aston Manor School, Birmingham.

Melting|smelting of Bronze at Isthmia

W Rostoker, M McNallan and E R Gebhard *

Abstract

In a context that can be dated between the 7th and mid-5th century BC, some lumps of a complex substance have been discovered. Analyses demonstrate a solidification structure containing Cu_20, $Sn0_2$, a probable $CaSn0_3$ and copper metal infiltrating the ceramic composite. The substance is interpreted either as a dross from bronze melting and remelting in a foundry operation or as a residue from an unusual co-smelting of copper and tin minerals to bronze metal.

Introduction

The Sanctuary of Poseidon at Isthmia stands with Olympia, Delphi and Nemea as one of the four great panhellenic religious centres of Greece. The first temple of Poseidon was built shortly after 700 BC but the presence of a few earlier votive objects shows that a cult had been established there perhaps a century earlier.

Fire destroyed the first temple at the time of the Persian Wars and its classical successor was badly damaged in another fire in 390 BC. Subsequently, the devastation by Roman troops under the command of the consul Mummius in 146 BC brought its prosperity to a halt for 200 years. After a Roman renaissance, final destruction came at the end of the 4th century AD. In 1952 Broneer uncovered the foundations of the classical temple and excavations followed. The architectural remains are presented in Broneer [1,2] and Gebhard[3].

Debris from the votive dedications in and around the archaic temple and from the Cyclopean wall was dumped into a large circular pit which at one time may have been used as a well or water reservoir. The pit is located 43m south of the SW corner of the classical temple and it measures ca.5 m in diameter by 19.75 m deep. Beginning at a depth of 2.20m below the rim and continuing to the bottom, the fill contained pottery that has been dated between the early 7th and the mid-5th centuries BC. There is no chronological stratification and it appears that the entire pit was filled within a short period of time soon after 450 BC (Broneer[2], pp 135-136).

In the lowest deposit in the pit, 15.80 to 19.75m below the rim, three irregularly-shaped lumps were recovered. Each was about the size of a small fist. They were covered with the green patina characteristic of copper and bronze objects but were clearly much less dense than metal. They could be fractured by a hammer blow but only with great difficulty. The fracture surface revealed colours and facetting characteristic of minerals but also fibrils of copper-like metal. Using a stereoptic microscope and a sharp dental probe, plastic deformability of the fibrils could be demonstrated in terms both of bending and indenting. The fibrils were provisionally regarded as metallic. The matrix appeared as largely black, polycrystalline, facetted and mineral-like.

On the basis of the pottery in the pit, the lumps belong to a period between the early seventh and mid-fifth century BC.

The analysis of these lumps has been part of a project to examine evidence of manufacturing methods in the period ca 800-146 BC. This paper adds to increasing demonstration that industrial activity existed in the immediate vicinity of the Sanctuary so close that industrial debris became mixed with the temple destruction debris[4-6]. The project was supported by a grant from the National Endowment for the Humanities matched by gifts from private individuals. Permission to work at Isthmia was granted by the Greek Archaeological Service through the then ephor for the Argolid-Corinthia, Mrs Krystalli. Our gratitude for valuable assistance goes to Professor Henry Immerwahr, Director of the American School of Classical Studies at Athens and to Dean Karl J Weintraub of the University of Chicago for their valuable assistance and support.

Preliminary Laboratory Analyses

Metallography easily established that the lump was a composite of copper metal and a complex ceramic substance. Three phases could be discerned in the ceramic substance. Two of these phases, one acicular and one rectangular in projection, were clearly primary crystallization products. The configuration of the three phases indicated that, at elevated temperatures, the ceramic substance had been a homogeneous liquid.

Using a radiation pyrometer calibrated against the melting temperatures of copper and nickel an incipient melting temperature of the lump heated in vacuum was about 1130°C. In the context of the test procedure where edge and angle slumping was the criterion, incipient melting signifies near but above a solidus temperature.

X-ray diffraction analysis of filings identified copper metal, Cu_20 and $Sn0_2$. The patterns of each of these three phases were strong and they accounted for all but five of 26 diffraction lines and all but one of the stronger lines.

Although the same phases appeared in all fields of view of the two metallographic sections taken, the proportions of phases varied widely and the morphology of the acicular phase showed a number of variants including a dendritic form. The interpenetrating matrix of copper metal indicates that a reducing atmosphere existed in contact with the liquid(s). The heterogeneous character of the metal/ceramic composite and the phase distributions suggested that the lumps were aggregates of liquid drops each of which might have somewhat different compositions or solidified at somewhat different rates.

Bronze Melting Dross

In view of the reasonably established existence of iron smelting near the Isthmia site[5] and foundry activity[4], it is a simple deduction to assume that the lumps represent dross skimmed from bronze melting and/or remelting operations.

Given the opportunity to oxidize, molten bronze will form a dross of the oxidation products which floats but does not cleanly separate from the metal underneath as would a normal fluid slag. It is therefore necessary to skim off the dross before pouring a casting. The skimming operation pulls off a quantity of metal as well since the dross adheres. There is good evidence of a foundry operation at Isthmia in terms of sprues or risers, parts of defective castings, spills and drips, bronze fragments of sizes appropriate for remelting[4]. However dross is not usually molten at the time of skimming since bronze can be poured at temperatures well below the melting temperature of copper.

Unfortunately binary tin bronzes are no longer a commercial commodity and have not been for some time so that the literature offers little that identifies the constitution of drosses. Accordingly they were synthesized. Pieces of bronze containing 5-8% Sn were remelted in crucibles using a gas-fired furnace with a vented roof. The metal was not covered with charcoal but was exposed to the combusted gases. The metal in the crucible was held above the melting temperature for about 60 minutes before removing from the furnace and cooling. The metal and dross were removed from the crucible en bloc when this was possible. Otherwise the crucible, metal and dross were sectioned as a unit with the intention of preserving all of the interfaces.

Using fireclay crucibles melting was performed at 1000^{o}, 1100^{o} and 1200^{o}C, respectively. At 1000^{o}, 1100^{o}C the dross layer was very thin and adherent to the underlying metal. The 1000^{o}C dross under metallographic examination was featureless or amorphous. The 1100^{o}C dross showed a few primary crystals but was otherwise featureless. Only the 1200^{o}C dross showed a profusion of primary crystallization products and a configuration of a matrix with crystal boundaries that signified a fully molten state as an initial condition at the high temperature. At 1200^{o}C the dross severely attacked the crucible and clearly a substantial quantity of that material had dissolved therein.

The 1200^{o}C melting and drossing experiment was repeated using a dense magnesia crucible. The dross was visibly liquid at the peak temperature but the crucible showed no evidence of being attacked.

Electron microprobe analysis identified the primary crystallization phase (1200^{o}C) as SnO_2 and the polycrystalline matrix as Cu_2O. Consistent with the obvious attack on the fireclay crucible by the molten dross, the latter showed minor amounts of a third phase which was rich in Al and Si. The same dross formed by oxidation in an MgO crucible with no attack showed only Cu_2O and SnO_2 and no Mg detectable.

Metallographically (Fig 1) the SnO_2 appears as fine, plate-like crystals in a matrix of Cu_2O. To develop this well matured morphology the SnO_2 must be a primary crystallization product growing out of a homogeneous melt.

More Detailed Analysis of the 'Lump' Artifact

There are three ceramic phases distinguishable in the ancient artifact, in addition to a dispersion of copper metal (Figs 2 and 3). Electron microprobe analysis identifies the acicular phase as SnO_2 with no other heavy elements associated. The flat plate, rectangular phase (Fig 3) is a composite of CaO and SnO_2. Its weight percent analysis is given as 25% CaO and 76% SnO_2 with a trace of Cu_2O. On a mole proportion basis this would signify a phase whose identity is $CaSnO_3$ or $CaO.SnO_2$. The matrix is Cu_2O. No other heavy elements were detectable.

There are significant differences between the 'lump' and the molten dross. The morphology of SnO_2 is acicular in the

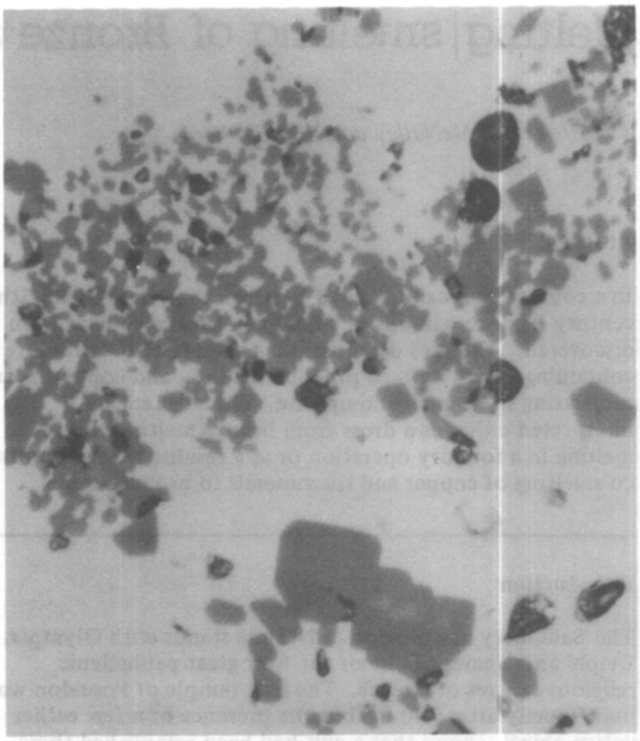

Figure 1 Mag X1000. Microstructure of bronze remelting dross formed at 1200^{o}C using a magnesia crucible, solidified over a period of about 15 minutes. The dispersed phase or primary crystallization product is SnO_2, the matrix is Cu_2O.

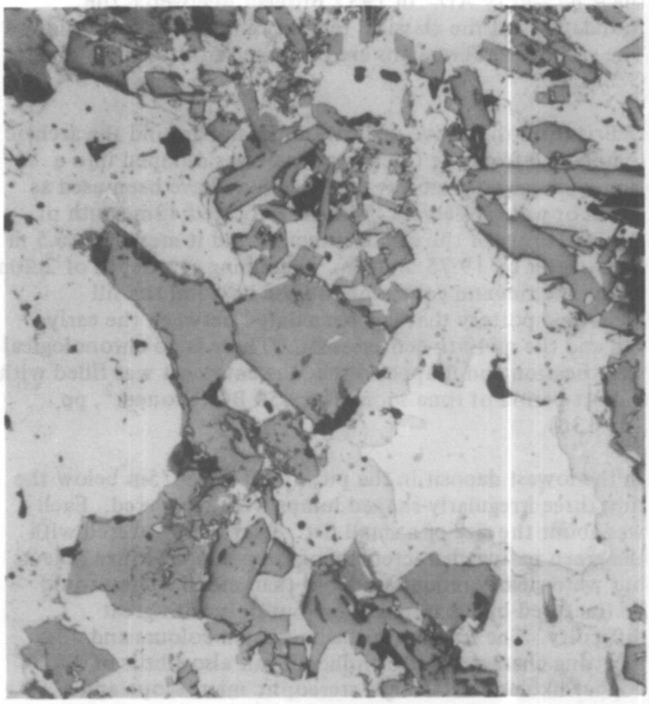

Figure 2 Mag X200. Microstructure of the ancient 'lump' artifact from Isthmia showing how the copper metal was embedded in the ceramic oxide composite.

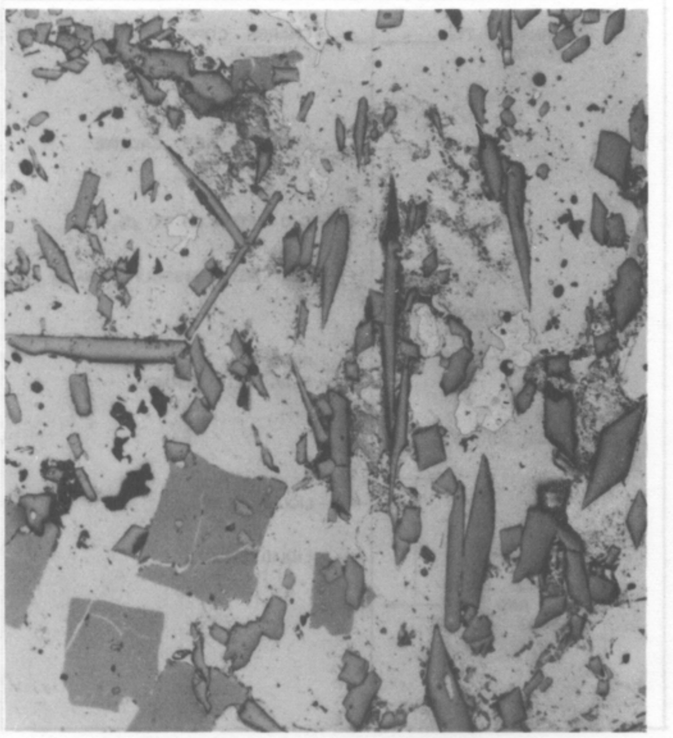

Figure 3 *Mag X200. A selected field of the Isthmia artifact which illustrates the well developed shapes of the $Sn0_2$ phase (acicular and rhombic) and the $CaSn0_3$ (probable) phase which is rectangular in shape. A few small particles of copper metal may be seen.*

lump and plate-like in the dross. Moreover, there is a very substantial difference in their principal dimensions; those of the lump being more than five times in size those of the dross. If the lumps were aggregates of manual skimmings their freezing rates would have been comparatively rapid to the dross cooling in the crucible in air. Clearly the lumps cooled at rates at least an order of magnitude more slowly.

The Bronze Smelting Alternative

It has been remarked by Muhly[7] and Charles[8] that, considering the large tonnage of tin involved in bronze production throughout the Mediterranean area for so many centuries in ancient times, there have been few finds of tin ingots or any form of metallic tin. Charles[8] speculated that bronze-making was a cementation process whereby a mixture of comminuted cassiterite, charcoal and flux was added to the surface of molten copper. Under such conditions the $Sn0_2$ would be reduced and immediately dissolved into the molten copper. If this were the case, the commerce would be in cassiterite rather than tin metal and, in fact, the existence of tin metal may not have been recognized for some time. An empiricist would simply recognize that the use of the mineral in the prescribed manner would produce a metal somewhat different in colour, lower melting, higher fluidity in casting and substantially improved mechanical properties.

Read[9] made an equally reasonable and equivalent proposition that bronze is most simply produced by the co-smelting of copper and tin minerals. To explore this proposition we have analyzed the thermodynamics of the co-smelting process using oxidic ores of copper and tin. A copper mineral such as malachite would dissociate to $Cu0$ at quite low temperatures and in any atmosphere composition. The oxide produce $Cu0$ would easily be reduced to Cu_20 in any combustion gas mixture that contains $C0$. The main event is the reduction of Cu_20 to metal.

The function of the process as outlined is regulated by two reduction equations. The first of these is:

$$Cu_20 + C0 \rightarrow 2\,Cu + C0_2$$

where

$$K = \frac{P_{C0_2}}{P_{C0}} = \exp\left[\frac{1.27 \times 10^4}{T} - 0.92\right] \qquad [2]$$

In the temperature range of 1200° – 1700°K, this requires for reduction to proceed a ratio P_{C0}/P_{C0_2} greater than 6×10^{-5} to 1.5×10^{-3}. These ratios are so small that almost any combustion process using air and charcoal which reaches and contains the temperature will assuredly reduce the oxide to metal.

The second reduction process involves:

$$Sn0_2 + 2C0 \rightarrow Sn + 2C0_2$$

where

$$K^{1/2} = \frac{P_{C0_2}}{P_{C0}} = \exp\left[1.75 - \frac{657}{T}\right] \qquad [2]$$

In the temperature range of 1200° – 1700°K, the reduction process requires a ratio of P_{C0}/P_{C0_2} greater than 0.256 - 0.3. This requires much more control of the air supply and the ratio of fuel to mineral in the charging. In general, this requires a relatively large input of charcoal and a restricted input of air so that sufficient combustion provides adequate tempeature and the combustion is substantially incomplete in order to maintain a high proportion of $C0$.

The reducibility of cassiterite is made easier by the solution conditions. The $Sn0_2$ is in solution with liquid Cu_20 as the artifact shows but, as the Cu_20 is progressively reduced, $Sn0_2$ is rejected from super-saturation. Thus the $Sn0_2$ can be considered at unit activity. However, the tin produced by reduction dissolves as a dilute solution in liquid copper. Under such conditions its activity would be substantially less than unity. Metallic copper being the majority component (greater than 90%) in the copper-tin solution can be considered to be at an activity of unity.

The activity of a component in a dilute liquid metal solution can be expressed as the product of the mole fraction of the component in the solution and its activity coefficient, which is determined by the nature of the chemical interaction between the solute and the solvent. Generally, the activity coefficient must be determined experimentally.

The copper-tin alloy system has been subjected to considerable study[10-12]. There is a strong chemical interaction between copper and tin, so that the interaction coefficient is substantially less than unity. The mole fraction of tin in a 5 weight % tin in copper alloy which could have been produced by ancient metallurgists is 0.027. Interpolating the available thermodynamic data by the methods suggested by Sigworth and Elliott[13] yields an activity coefficient of 0.063 in this alloy at 1200°C. Therefore, the activity of tin in the alloy would be 0.0017 with respect to pure liquid tin.

The tin reduction reaction equilibrium constant is now defined as:

$$K = \frac{a_{Sn}^{1/2} \; P_{CO_2}}{a_{SnO_2}^{1/2} \; P_{CO}} = \exp\left[1.75 - \frac{657}{T}\right]$$

With the activity of SnO_2 equal to unity and the activity of tin equal to 0.0017, the minimum ratio of the P_{CO}/P_{CO_2} is now only 0.011 at 1200°C. This allows a much more efficient combustion process and a far less demand on the level of CO content in the hot gases.

Although both copper and tin can be reduced from their oxides at lower temperatures, the reduction process must nevertheless be operated above about 1150°C (1423°K) for purposes of slagging. The metal recovery in a smelting process is a liquid/liquid separation wherein the rock components of the ore are converted to a light, liquid slag which floats above the denser liquid metal and through which droplets of liquid metal can settle and efficiently collect. Slags do not commonly melt below the 1150°C level. These slags are commonly of the system $FeO - SiO_2$.

Consider the use of a short shaft furnace of a type described in Tylecote[14], which is bottom-tapped below the tuyeres. The charge is, for example, an appropriate mixture of malachite, cassiterite, charcoal and fluxes which is continually replenished as the column of reagents descend towards the tuyeres. During this descent the temperature rises and the malachite calcines to CuO. Further down the CO/CO_2 ratio of the hot, rising gases are sufficient to reduce CuO to Cu_2O. At a lower level the Cu_2O melts and dissolves the cassiterite and droplets of liquid oxide solution percolate through the hot charcoal bed. At some location (if they reach it), the conditions are appropriate for reduction of both metals to the alloy bronze which collects in a pool at the bottom protected from re-oxidation by a liquid slag layer.

If some of these liquid oxide solution drops drip toward the furnace wall just above the tuyeres, they may be incompletely reduced, trapped and obstructed from further descent and aggregate slowly until the furnace is shut down probably because the wall has been thinned out or cracked. Then the furnace would be knocked down and rebuilt. Some of our incompletely reduced agglomerates would be lost in the debris. These ideas are illustrated in Fig 4. Unless limestone were a part of the charge, this does not account for the $CaSnO_3$ phase in the lumps.

Interpretation

We are assured that there is no known, naturally-occurring, mineral that is a physical mixture of native copper, cuprite and cassiterite. It seems necessary to recognize that these objects are man-made and residual from some melting or smelting process.

Consider first the possibility of a foundry operation in which liquid bronze is produced by melting in a crucible positioned in a pit-furnace. Dross would form over the molten metal and would have to be skimmed off before pouring castings. Two considerations make this an unlikely rationale.

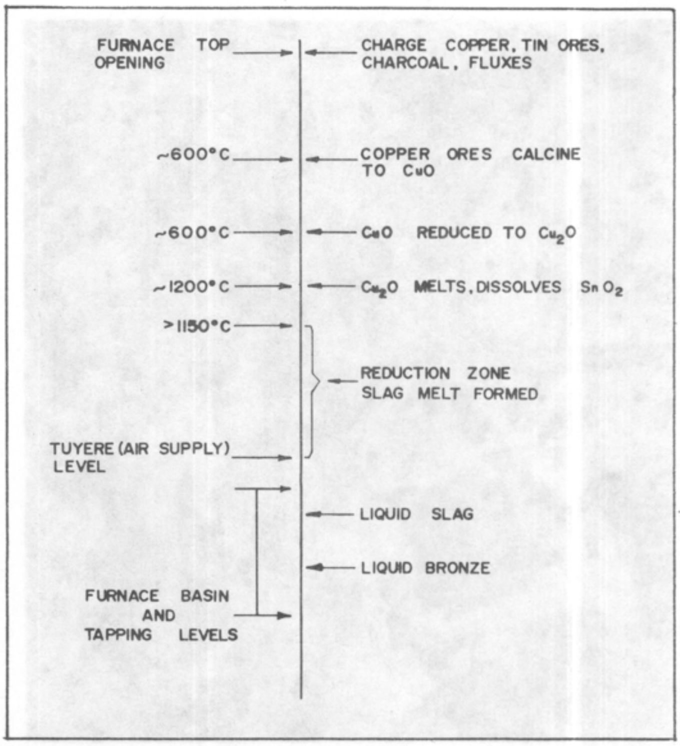

Figure 4 Diagrammatic view of temperatures and relative positions in the vertical centreline of a shaft furnace hypothetically co-smelting copper and tin ores to bronze.

Molten dross is very aggressive, the crucible would be rapidly attacked and the dross would exhibit significant and easily detectable amounts of Al and Si. These are absent from the ancient artifacts. The skimmed dross would cool very rapidly. The present experiments demonstrate that the primary crystallization products are much too coarse to be consistent with simple cooling rates involving times of only several minutes. There are also questions of a functional nature. Molten dross requires a temperature above about 1150°C which is much too high as a sensible melting operation for bronze. Moreover any intelligent foundryman would keep a charcoal cover over the metal during melting.

The coarse crystalline nature of the lump as indicated both by metallography and the facetted fracture surface suggests a very slow cooling (and freezing) rate. This structural nature is consonant more with an identity as a residuum from a shaft furnace. A shaft furnace would serve well as a high productivity bronze remelting facility much as the modern cupola serves for cast iron. The top charge would be charcoal, appropriately fragmented bronze scrap and virgin metals. The air blast through tuyeres could be tuned to a much lower CO/CO_2 ratio without damage (oxidation) to the metal and with a more efficient combustion than is tolerable in smelting.

We can come to grips now with the CaO content of the lumps and the absence of Al_2O_3 and SiO_2. Clay in the vicinity of Corinth and Isthmia is largely Illite substantially admixed with $CaCO_3$[6]. It fires well and would serve for furnace wall construction. However it would not be possible for molten dross to attack the furnace wall by selectively leaching only CaO. There would be commeasurate pickup of the other intrinsic oxides of the clay. The bedrock at Isthmia is limestone. The furnace basin holding the liquid metal at the base of the shaft furnace would be likely pure calcined CaO and a dross forming on the liquid metal could absorb that oxide alone.

During the melt-down stage the internal atmosphere is likely to be too reducing for dross formation. But when the furnace is tapped and drained of liquid metal, small quantities of metal occluded in the basin surface would oxidize readily. When melting was re-initiated the new liquid metal would simply cover over the dross. Some might float up and be reduced but surface tension would trap a great deal and preserve its oxidized state. Finally when the furnace campaign was over the basin would cool very slowly, the furnace superstructure would be demolished and the basin covered over. The lime shell would ultimately re-carbonate. Since the temple site knew several reconstructions the lumps would be incorporated in the debris of new building.

This contrived scenario unfortunately fits either a bronze remelting and foundry activity or a bronze co-smelting operation. The latter would have a top slag but it would be drained off before the metal. The events after tapping the metal would produce the same results in either circumstance. What remains is the high melting temperature of the 'lump' identity and the assurance that the substance was almost or totally liquid before freezing. Is it reasonable for the liquid metal tapped from the basin to be superheated to over 1150°C? The co-smelting operation certainly could expect this in the interests of tapping a fluid slag. It is not so obviously reasonable as a foundry practice. Nevertheless the ambiguity must be regarded as not well resolved. In fact a combination of co-smelting and scrap remelting is also possible.

Acknowledgements

The authors wish to express their appreciation to Dr Ian Steele of the Department of Geological Sciences at the University of Chicago and to Dr Werner Baur of the Department of Geological Sciences at our University for electron microprobe phase identifications, and to Mr James Dvorak, Brunswick Corporation for the difficult metallography and the micrographs presented in this paper.

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Note

Bronze Ram for an Early Ship

Mediterranean ships of the Greek and Roman periods are well-known for their copper and bronze nails, lead sheathing and lead anchor stocks. But the latest find places marine metal-work in quite a different order of magnitude. Recently, a conference was held in Haifa to discuss the finding of the Athlit Ram which was found a year or two ago off the coast to the south of Haifa. This bronze casting was designed to reinforce the prow of a war-ship of the period around 400 BC and turn it into a deadly weapon. Weighing about 400 kg it must be one of the largest castings made in the West and might be compared with the Chinese cauldrons of an earlier epoch. It is a straight tin-bronze and, apparently, a one-piece casting secured to the ship by large copper or bronze nails. *after Honor Frost (Int J of Nautical Archaeology and Underwater Explor, 1982*, **11** *(1), 59-61)*

Letter to the Editor

Dear Sir,

In your Journal 1981, Part 1, information is given on the results of examinations of early finger rings from Greece (17th - 14th century BC) presented by Dr G Varoufakis during the Symposium on Early Metallurgy in Cyprus in June 1981.

The results of these analyses correspond to my hypothesis, preliminarily published in 1960, 1963 and 1970 and presented during the Seminar on Pyrotechnology in Smithonian Institution in 1979. According to my hypothesis the high-nickel iron was smelted from the iron-nickel-cobalt-arsenic ore. This was the famous Chalybean iron, praised by Classical authors.

Prof dr Jerzy Piaskowski

Ancient Chinese Bronze: Neutron activation analysis provides effective means of studying ancient bronze seals

L S Chuang, L S Kwong and Y C Wong

1 Introduction

The ancient Chinese bronze seals (the photographs of some of the typical seals are shown in Fig 1) are typically of the size of 1 cm x 1 cm to 2.5 cm x 2.5 cm in perimeter 1 to 2.5 cm in height, and weigh about 10 gm. As the size is so small they cannot be drilled to obtain an adequate sample for wet chemical or spectrometric analysis for their elemental contents. The rather large thickness and irregular shape of the seals make X-ray fluorescence analysis, resulting from X-ray or charged particle irradiation of the seals, extremely difficult if not impossible. As a result, the elemental contents of ancient Chinese bronze seals have scarcely ever been studied. However, neutron activation analysis is an effective method which can be conveniently used. Therefore, an attempt was made to study the elemental contents of the 250 bronze seals available in the University Art Gallery of The Chinese University of Hong Kong, using the 14 MeV neutron generator installed in the University Science Centre[1]. These seals were grouped into 3 different periods of production based on the seal shape, the dimensions, the button form, and the engraved characters and the official name. 180 belong to the Warring State Period (475 - 221 BC), 46 belong to the Han (206 BC - 220 AD) and Southern & Northern Dynasty (420 - 589 AD); and 9 belong to T'ang (618 - 906 AD) and Ming Dynasty (1368 - 1644 AD). It should be noted that the date of production is not engraved on any private or official seals of pre-Sui dynasty (581 AD). Therefore, it was not possible to know the specific date for each individual seal any closer than the present information, nor, we are afraid, will it be possible in the future.

The seals were found to be composed of Cu, Sn and Pb as the major constituents and some impurities such as Sb, As, Zn, Fe and Mg as the minor or trace constituents. A gamma-ray spectrometer composed of an ORTEC 81 cm^3 (Ge(Li) coaxial gamma-ray detector and an ORTEC 1024-channel pulse height analyzer was used for the spectroscopic measurements of the gamma-rays emitted from the 14-MeV neutron induced activities in the seals which give the direct measures of the kind and the amount of the elements involved. Corrections for the attenuation of the gamma-rays in thick and irregularly shaped bronze seals were duly applied [2,3,4]. With a plausible assumption that the elemental contents other than those measured are negligibly small[5], the absolute amount for each of the measured elements was obtained from the total mass of the seal and the mass ratio of the contents. The results of analysis for each of the 235 seals together with the information on the historical and structural aspects are presented in Table 1. In addition, a comparison of the present results with those of other published ancient Chinese bronze articles is also attempted.

2 Results and Discussion

The results of the analyses are tabulated in Table 1. Disregarding the 15 seals which are not typical, eg seals containing only Sn or Pb in the major constituents and those containing higher percentage of Sn or Pb than Cu (eg Cu - 8.23%, Sn - 54.7% and Pb - 33.9%; Cu - 26.3%, Sn - 7.5% and Pb - 66.0%), the rest of 235 bronze seals were considered for the average percentage content for each of the analyzed constituents according to the three time-periods of origin of the seals – these results are also provided in Table 1.

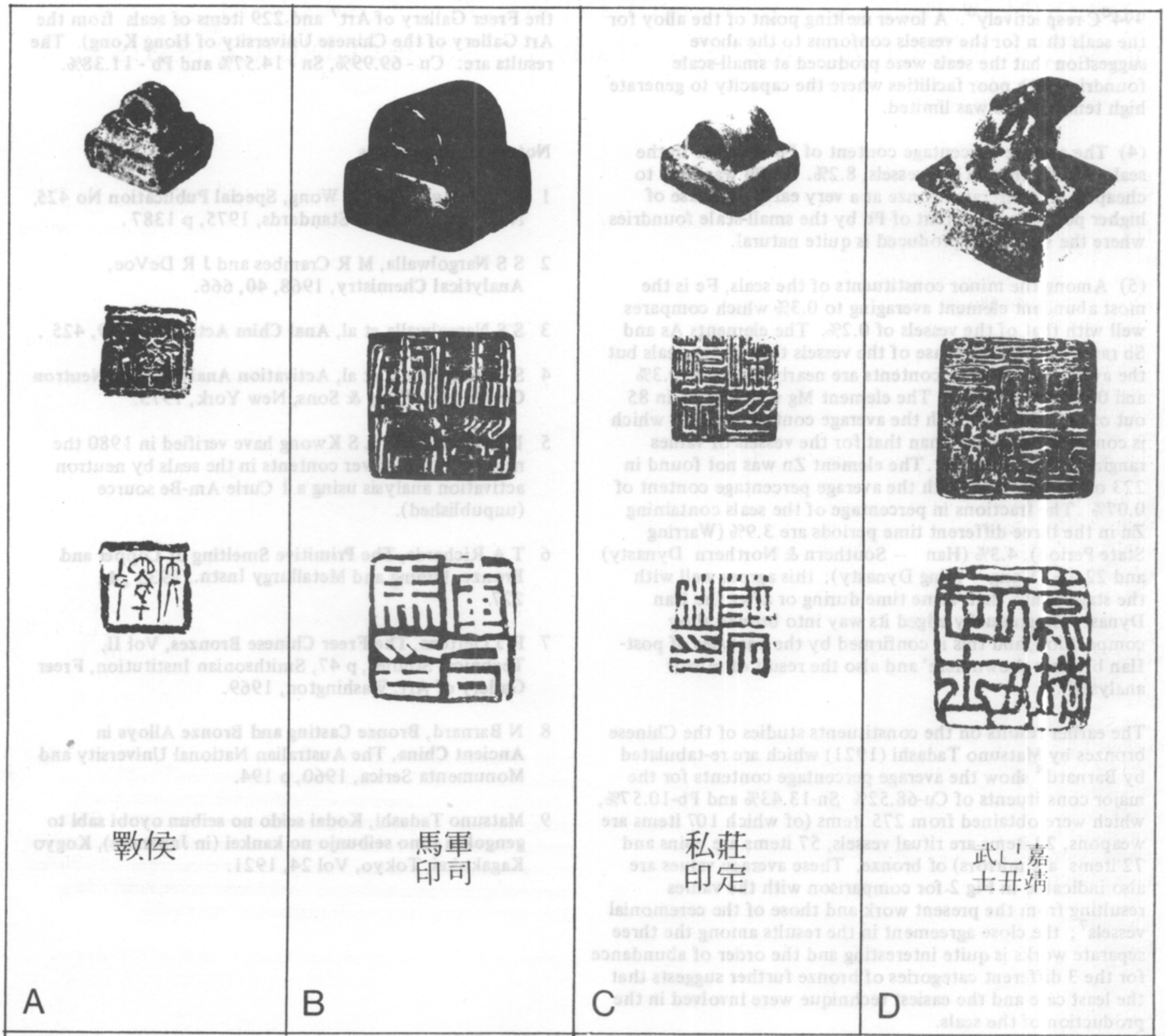
Inspection of Table 1 shows that slightly higher use of Pb than Sn in the T'ang – Ming Dynasty as compared with the earlier periods and lower impurity of As in the Warring State period as compared with the later periods are noted. The data for the individual seals show no relationship between the composition and type of the seal shape. A point worth noting is that the three official seals from Han-Southern & Northern Dynasty show consistently higher Cu content of the average percentage of 84.4 ± 7.2% as compared to the value of 64.7 ± 15.6% for the rest of the 180 private seals of the same time period. The content of Sn and Pb in these 3 official seals is low with the average percentage content of 3.8 ± 0.3% for Sn and 10.0 ± 5.9% for Pb as compared to the values of 19.3 ± 13.9% for Sn and 14.5 ± 10.1% for Pb for the other private seals of the same time period. Considering the relatively high melting point 1040°C of the Cu-Sn alloy of 95% : 5% mixture of the 3 official seals[6], and the higher cost of Cu metal as compared to Sn and Pb, it is tempting to interpret from the information gathered that these 3 official seals must have been produced in a well-organised foundry capable of producing higher temperature. On the other hand, the other 177 private seals need about 875°C for melting the Cu-Sn alloy of 80% : 20% as will be discussed more fully later, and must have been produced in the foundries with poorer facilities. The higher content of Zn in all of the 3 official seals as compared to the other 177 private seals of the same time period further suggests that the foundry for the official seals is definitely different from those producing the private seals.

Distribution of the major and the minor/trace constituents in the 229 bronze seals are shown in histograms in Fig 2. In the same figures the distribution of the major and the minor/trace constituents in 97 ceremonial Chinese bronze vessels in the collection of the Freer Gallery of Art[7] is also provided for comparison. The following facts and interpretations are deduced from the results of the comparison between the distribution for the seals and the vessels

(1) The major constituent elements, Cu, Sn and Pb make up, in overall average, 98.7% for the seals and 992.% for the vessels of the total composition of the artifacts – less impurities are contained in the alloy for the vessels than for the seals.

(2) The wide range of Sn and Pb contents suggests that control of the alloy composition was not rigid and the product is the result of mixing ores of varied composition[7]. The wider spread of the range of Sn and Pb in the seals than in the vessels further suggest that the seals which are small in size and simple to cast were made at many small-scale foundries while the vessels were produced at a limited number of better-organised large-scale foundries.

(3) The average ratio of Cu to Sn content for the seals and the vessels are 80% : 20% and 90% : 10% respectively. This implies that the melting points of the Cu-Sn alloys used for the seals and for the vessels are about 875°C and



Code	Time Period of Origin	Type of the Figure	Size (cm) Base	Size (cm) Height
A	Warring State Period	Dais Button	1.35 x 1.35	1.35
B	Han - Southern and Northern Dynasty (Official Seal)	Tile Button	2.56 x 2.53	2.46
C	Han - Southern and Northern Dynasty (Private Seal)	Tile Button	1.73 x 1.67	1.34
D	T'ang - Ming Dynasty	Rabbit Button	3.31 x 3.08	3.75

Fig 1 Photographs of the typical Chinese bronze seals; the seal shape, the inscription and the characteristics of the letters are shown from top to bottom:

994°C respectively[6]. A lower melting point of the alloy for the seals than for the vessels conforms to the above suggestion that the seals were produced at small-scale foundries with poor facilities where the capacity to generate high temperature was limited.

(4) The average percentage content of Pb is higher in the seals, 13.7%, than in the vessels, 8.2%. As Pb was used to cheapen or adulterate bronze at a very early date, use of higher percentage content of Pb by the small-scale foundries where the seals were produced is quite natural.

(5) Among the minor constituents of the seals, Fe is the most abundant element averaging to 0.3% which compares well with that of the vessels of 0.2%. The elements As and Sb range wider in the case of the vessels than in the seals but the average percentage contents are nearly the same 0.3% and 0.2%, respectively. The element Mg was missing in 85 out of the 235 seals with the average content of 0.2% which is considerably higher than that for the vessels of values ranging 0.001 - 0.007% . The element Zn was not found in 223 of the 235 seals with the average percentage content of 0.07% . The fractions in percentage of the seals containing Zn in the three different time periods are 3.9% (Warring State Period), 4.3% (Han – Southern & Northern Dynasty) and 22.2% (T'ang – Ming Dynasty); this agrees well with the stagement[7] that 'some time during or after the Han Dynasty Zn gradually edged its way into bronze alloy composition, and this is confirmed by the analyses of post-Han bronzes shown here' and also the result of mirror analyses[8].

The earlier results on the constituents studies of the Chinese bronzes by Matsuno Tadashi (1921) which are re-tabulated by Barnard[8] show the average percentage contents for the major constituents of Cu-68.52% ,Sn-13.43% and Pb-10.57%, which were obtained from 275 items (of which 107 items are weapons, 29 items are ritual vessels, 57 items are coins and 72 items are mirrors) of bronze. These average values are also indicated in Fig 2 for comparison with the values resulting from the present work and those of the ceremonial vessels[7]; the close agreement in the results among the three separate works is quite interesting and the order of abundance for the 3 different categories of bronze further suggests that the least care and the easiest technique were involved in the production of the seals.

The overall average percentage content of the major constituents of ancient Chinese bronze can then be determined, with reasonably good statistics, from 601 items (ie 275 items of weapons, vessels, coins and mirrors from Matsuno Tadashi[9] 97 items of ceremonial vessels from the Freer Gallery of Art[7] and 229 items of seals from the Art Gallery of the Chinese University of Hong Kong). The results are: Cu - 69.99%, Sn - 14.57% and Pb - 11.38%.

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Acknowledgements

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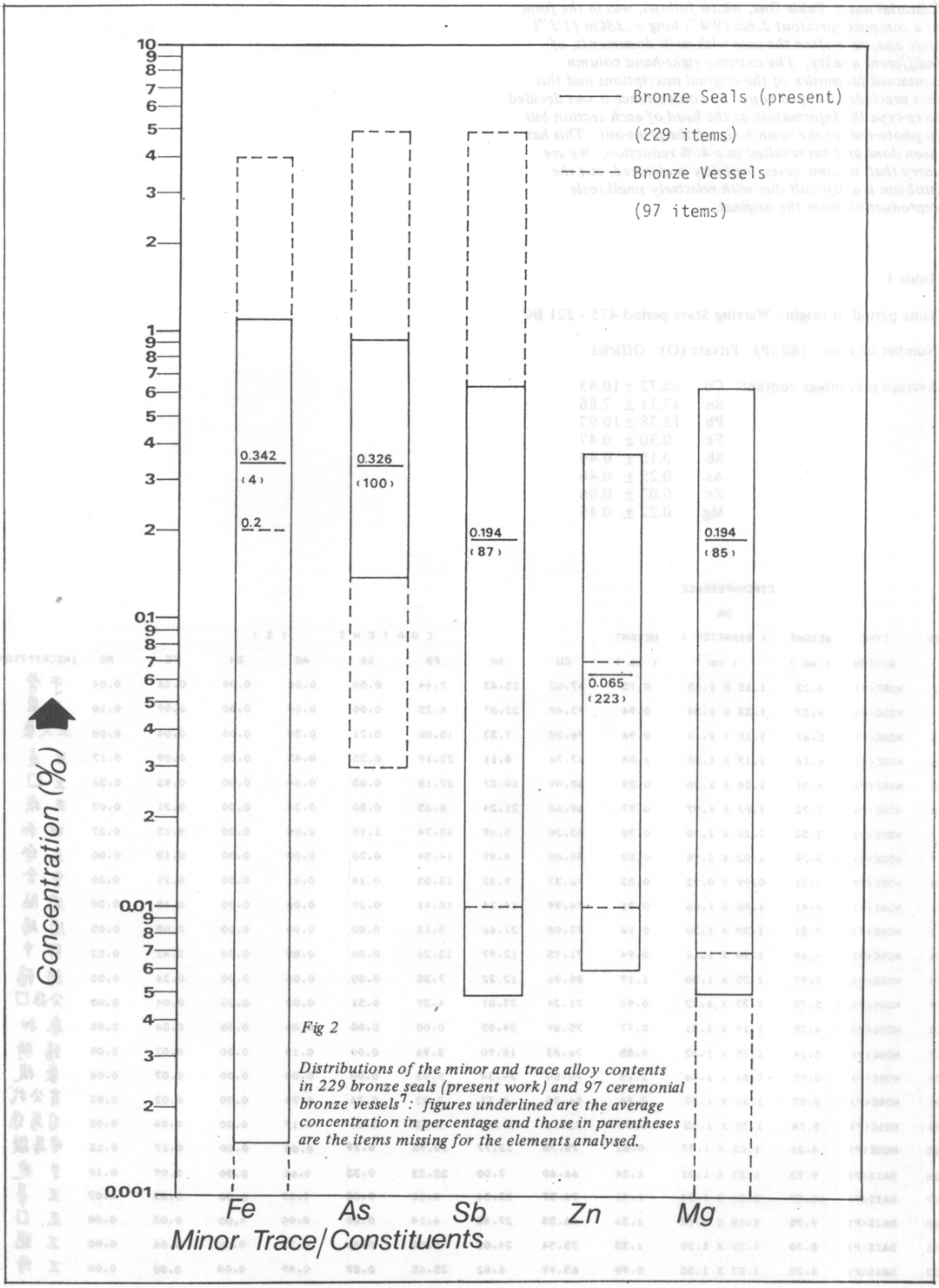


Fig 2

Distributions of the minor and trace alloy contents in 229 bronze seals (present work) and 97 ceremonial bronze vessels[7]: figures underlined are the average concentration in percentage and those in parentheses are the items missing for the elements analysed.

Editorial note: *Table One, which follows, was in the form of a computer-printout 2.8m (9'4") long x .380m (1'3") wide and, as is often the case with such documents, of indifferent quality. The extreme right-hand column contained facsimiles of the original inscriptions and this fact precluded a typed copy. In consequence it was decided to re-type the information at the head of each section but to photo-reduce the main body of the print-out. This has been done and has resulted in a 40% reduction. We are sorry that, in some cases, legibility is affected, but the problem is a difficult one with relatively small-scale reproduction from the original.*

Table 1

Time period of origin: **Warring State period** 475 - 221 BC

Number of seals: 180 (P): Private (O): Official

Average percentage content:		
	Cu	68.72 ± 10.43
	Sn	17.11 ± 7.86
	Pb	13.38 ± 10.97
	Fe	0.30 ± 0.47
	Sb	0.15 ± 0.44
	As	0.29 ± 0.46
	Zn	0.07 ± 0.06
	Mg	0.22 ± 0.45

CODE	TYPE BUTTON	WEIGHT (gm)	CIRCUMFERENCE OR (DIAMETER) (cm)	HEIGHT (cm)	CONTENT (%) CU	SN	PB	SB	AS	ZN	FE	MG	INSCRIPTION
1	NOSE(P)	4.22	1.15 X 1.15	0.75	67.02	25.43	7.44	0.00	0.00	0.00	0.06	0.04	于胥
2	NOSE(P)	6.22	1.33 X 1.34	0.94	73.49	22.07	4.25	0.00	0.00	0.00	0.09	0.10	王匿
3	NOSE(P)	5.67	1.18 X 1.14	0.96	76.20	7.33	15.80	0.21	0.50	0.00	0.04	0.00	王大乘
4	NOSE(P)	6.16	1.17 X 1.20	1.04	67.76	8.11	23.19	0.25	0.43	0.00	0.09	0.17	王虘
5	NOSE(P)	4.81	1.20 X 1.20	0.89	60.09	10.07	27.18	0.83	0.64	0.00	0.93	0.26	王□
6	NOSE(P)	7.72	1.97 X 1.97	0.97	69.60	21.24	8.65	0.00	0.24	0.00	0.21	0.07	王疾
7	NOSE(P)	3.50	1.20 X 1.20	0.78	52.20	5.49	40.74	1.15	0.00	0.00	0.15	0.27	田和
9	NOSE(P)	3.79	1.02 X 0.98	0.82	80.08	4.99	14.54	0.20	0.00	0.00	0.18	0.00	支壁
10	NOSE(P)	3.21	0.99 X 0.92	0.82	76.37	9.32	13.55	0.14	0.41	0.00	0.21	0.00	曹舍
11	NOSE(P)	4.41	1.06 X 1.06	0.91	74.99	14.14	10.41	0.29	0.00	0.00	0.18	0.00	周隧
12	NOSE(P)	7.81	1.30 X 1.30	0.96	73.08	21.66	5.13	0.00	0.00	0.00	0.08	0.05	周竭
14	NOSE(P)	4.69	1.16 X 1.16	0.94	71.95	12.97	12.26	0.00	0.88	0.00	1.42	0.52	鄂中
15	NOSE(P)	9.97	1.35 X 1.30	1.19	80.06	12.22	7.35	0.00	0.00	0.00	0.36	0.00	劫猲
17	NOSE(P)	5.78	1.22 X 1.22	0.90	71.24	23.81	4.39	0.51	0.00	0.00	0.04	0.00	公孫□
18	NOSE(P)	4.38	1.19 X 1.21	0.77	75.89	24.05	0.00	0.00	0.00	0.00	0.06	0.00	秦扣
19	NOSE(P)	5.24	1.35 X 1.32	0.85	76.83	18.90	3.96	0.00	0.15	0.00	0.07	0.09	猲騎
20	NOSE(P)	8.95	1.54 X 1.46	1.14	70.50	24.34	5.03	0.00	0.00	0.00	0.07	0.06	叅徙
21	NOSE(P)	6.07	1.30 X 1.30	0.96	86.50	4.73	7.22	0.76	0.74	0.00	0.02	0.03	肖公弒
24	NOSE(P)	5.74	1.35 X 1.35	0.98	72.11	21.72	5.82	0.06	0.17	0.00	0.06	0.05	司馬係
25	NOSE(P)	4.21	1.05 X 1.07	0.82	75.78	12.77	10.96	0.19	0.00	0.00	0.17	0.13	司馬顯
26	DAIS(P)	9.93	1.23 X 1.21	1.24	66.60	7.00	25.23	0.35	0.62	0.00	0.09	0.10	孛建
27	DAIS(P)	11.59	1.21 X 1.24	1.41	76.59	23.36	0.00	0.00	0.00	0.00	0.03	0.02	王尋
30	DAIS(P)	9.75	1.18 X 1.18	1.36	66.35	27.48	6.14	0.00	0.00	0.00	0.03	0.00	王□
31	DAIS(P)	8.20	1.27 X 1.20	1.35	75.54	24.05	0.00	0.00	0.35	0.00	0.06	0.00	王惡
32	DAIS(P)	6.20	1.32 X 1.38	0.98	65.99	6.82	25.65	0.09	0.49	0.00	0.08	0.08	王倚

33	DAIS(P)	7.21	1.20 X 1.20	1.20	70.18	22.52	6.71	0.00	0.00	0.00	0.23	0.35	王宜
34	DAIS(P)	5.90	1.30 X 1.30	1.00	74.64	24.94	0.00	0.18	0.00	0.00	0.13	0.11	左市
36	DAIS(P)	5.65	1.15 X 1.15	1.15	65.00	24.19	9.49	0.00	0.00	0.00	0.97	0.35	成忠
37	DAIS(P)	8.24	1.37 X 1.37	1.07	79.26	20.15	0.00	0.00	0.23	0.00	0.16	0.20	審佗
39	DAIS(P)	7.22	1.05 X 1.05	1.32	71.19	21.72	4.55	1.95	0.42	0.14	0.03	0.00	長章
40	DAIS(P)	4.86	1.28 X 1.28	0.92	76.20	22.93	0.00	0.00	0.00	0.00	0.29	0.58	長武
41	DAIS(P)	5.52	1.35 X 1.37	0.85	65.98	13.65	19.48	0.13	0.66	0.00	0.11	0.00	長務
42	DAIS(P)	4.80	0.90 X 0.94	1.07	67.99	23.56	8.43	0.00	0.00	0.00	0.00	0.03	吳道
43	DAIS(P)	9.96	1.25 X 1.25	1.40	62.83	10.08	26.66	0.06	0.27	0.00	0.07	0.02	宗睨
44	DAIS(P)	8.33	1.28 X 1.28	1.17	70.30	9.86	18.86	0.09	0.29	0.00	0.31	0.29	胥間
45	DAIS(P)	10.95	1.30 X 1.30	1.30	75.52	24.43	0.00	0.00	0.00	0.00	0.05	0.00	敢怠
46	DAIS(P)	9.23	1.18 X 1.18	1.40	78.68	21.29	0.00	0.00	0.00	0.00	0.04	0.00	敢恭
47	DAIS(P)	4.20	1.00 X 1.50	0.85	76.25	15.56	7.85	0.15	0.00	0.00	0.14	0.04	不害
48	DAIS(P)	5.68	1.37 X 1.30	0.86	73.74	20.96	4.65	0.44	0.00	0.00	0.14	0.08	廣口右
49	DAIS(P)	7.12	1.35 X 1.35	1.12	72.19	24.71	1.41	0.48	0.42	0.00	0.28	0.52	路肯
50	DAIS(P)	9.13	1.32 X 1.34	1.36	73.22	22.41	3.35	0.09	0.25	0.00	0.27	0.43	客嬰
51	DAIS(P)	7.46	1.32 X 1.36	1.30	80.42	11.03	7.22	0.00	0.00	0.00	0.47	0.85	孫臥
52	DAIS(P)	3.21	0.99 X 0.91	0.77	87.17	12.83	0.00	0.00	0.00	0.00	0.00	0.00	徐杜
54	DAIS(P)	11.03	1.35 X 1.35	1.35	70.63	23.43	5.64	0.00	0.00	0.00	0.14	0.16	侯毅
55	DAIS(P)	6.23	1.21 X 1.18	0.97	72.11	9.28	16.87	0.16	0.74	0.00	0.66	0.19	侯洋
56	DAIS(P)	10.52	1.37 X 1.37	1.37	72.76	16.90	10.22	0.00	0.00	0.00	0.06	0.05	侯湯
57	DAIS(P)	4.91	1.22 X 1.22	1.08	79.03	19.80	0.00	0.00	0.00	0.00	0.56	0.60	事政
58	DAIS(P)	8.20	1.42 X 1.42	1.14	67.74	21.90	10.05	0.08	0.00	0.00	0.17	0.08	事肩
60	DAIS(P)	8.73	1.36 X 1.34	1.30	69.11	23.22	6.89	0.07	0.00	0.00	0.04	0.33	高癸
62	DAIS(P)	10.04	1.36 X 1.28	1.47	64.20	24.28	11.18	0.05	0.13	0.00	0.08	0.07	喬左
64	DAIS(P)	9.49	1.15 X 1.15	1.93	76.58	21.50	1.80	0.05	0.00	0.00	0.06	0.00	鄧臣
65	DAIS(P)	7.00	1.24 X 1.19	1.14	71.68	20.21	6.88	0.00	0.76	0.00	0.22	0.26	桑習
66	DAIS(P)	8.63	1.25 X 1.20	1.34	75.07	24.85	0.00	0.00	0.00	0.00	0.08	0.00	桑德
67	DAIS(P)	7.79	1.40 X 1.40	0.79	75.97	23.77	0.00	0.00	0.19	0.00	0.06	0.00	赫高
70	DAIS(P)	8.48	1.33 X 1.33	1.00	69.92	22.16	7.78	0.09	0.00	0.00	0.05	0.00	胥虒
72	DAIS(P)	7.19	1.32 X 1.32	1.04	71.08	21.55	6.72	0.00	0.30	0.00	0.22	0.14	趙豐
73	DAIS(P)	4.76	1.19 X 1.19	0.80	77.11	22.47	0.00	0.05	0.22	0.00	0.15	0.00	衛佐
74	DAIS(P)	6.66	1.23 X 1.14	1.05	73.83	26.07	0.00	0.00	0.00	0.00	0.10	0.00	萬口
75	DAIS(P)	5.32	1.06 X 1.06	0.90	76.22	12.94	10.57	0.00	0.00	0.00	0.27	0.00	戴約
76	DAIS(P)	7.48	1.10 X 1.10	1.23	67.09	25.35	7.36	0.00	0.00	0.00	0.19	0.00	鄒敢之
78	DAIS(P)	7.99	1.26 X 1.30	1.25	75.79	23.70	0.00	0.00	0.00	0.00	0.19	0.32	蘇疾
79	DAIS(P)	4.60	1.10 X 1.10	1.10	61.35	28.53	9.24	0.00	0.00	0.00	0.46	0.41	郎敢
80	DAIS(P)	8.85	1.30 X 1.30	1.18	67.97	11.23	20.29	0.10	0.36	0.00	0.05	0.00	口目
81	DAIS(P)	4.20	1.02 X 1.02	0.96	72.38	27.32	0.00	0.00	0.00	0.00	0.14	0.16	口睨
82	DAIS(P)	5.53	1.19 X 1.16	1.05	65.05	26.73	6.84	0.09	0.23	0.00	0.84	0.22	口飲
83	DAIS(P)	5.18	1.15 X 1.15	0.95	64.16	19.52	15.13	0.65	0.41	0.00	0.13	0.00	口口
94	DATS(P)	4.43	1.04 X 1.02	1.14	66.92	28.16	4.75	0.06	0.00	0.00	0.12	0.00	口口
85	DAIS(P)	7.80	1.40 X 1.35	1.30	71.46	20.06	6.84	0.00	0.00	0.34	0.50	0.80	上官得
86	DAIS(P)	5.83	1.15 X 1.17	1.05	69.15	16.71	13.09	0.18	0.00	0.00	0.62	0.25	于尺章
89	DAIS(P)	7.77	1.32 X 1.32	1.07	71.81	10.77	16.93	0.13	0.21	0.00	0.02	0.00	淳于敢
91	DAIS(P)	3.98	1.10 X 1.10	0.82	78.31	21.58	0.00	0.00	0.00	0.00	0.06	0.05	口口郭
92	DAIS(P)	4.74	1.14 X 1.20	0.85	77.69	8.81	13.25	0.21	0.00	0.00	0.04	0.00	口榕
93	DAIS(P)	4.34	1.25 X 1.16	0.75	72.41	18.96	8.49	0.00	0.00	0.00	0.10	0.05	公孫談
94	DAIS(P)	2.22	1.02 X 1.02	0.58	61.89	9.17	28.60	0.00	0.00	0.00	0.34	0.00	口郭
95	DAIS(P)	2.81	0.96 X 0.80	NIL	66.94	32.97	0.00	0.00	0.00	0.00	0.09	0.00	陳邑
96	DAIS(P)	4.70	(1.09)	1.04	96.28	3.43	0.00	0.18	0.00	0.00	0.11	0.00	戲昇
97	NOSE(P)	1.26	1.28 X 1.28	0.61	45.89	30.07	21.15	0.00	0.72	0.00	0.91	1.26	萬金
98	NOSE(P)	10.46	1.56 X 1.69	0.98	76.74	17.39	4.98	0.00	0.00	0.56	0.20	0.13	大利

99	NOSE(P)	0.73	0.62 X 0.62	0.70	36.34	16.29	38.77	0.00	2.02	5.78	0.52	0.28	福壽
100	NOSE(P)	3.69	(1.08)	0.92	63.32	11.15	25.35	0.00	0.00	0.00	0.18	0.00	敬行
101	NOSE(P)	11.76	(1.53)	1.18	86.79	9.15	3.82	0.00	0.21	0.00	0.02	0.00	中臣
102	NOSE(P)	1.96	(1.05)	0.77	73.98	11.18	11.35	0.40	1.46	0.00	0.87	0.76	慈之
103	NOSE(P)	2.31	(1.09)	0.79	82.70	15.80	0.00	0.00	1.09	0.00	0.18	0.15	慈命
104	DAIS(P)	4.78	1.17 X 1.17	1.08	58.12	14.95	25.77	0.10	0.27	0.00	0.29	0.50	敬事
105	DAIS(P)	6.44	1.08 X 1.08	1.29	66.52	27.19	5.67	0.26	0.32	0.00	0.04	0.00	敬事
106	DAIS(P)	6.87	1.25 X 1.25	1.22	74.58	13.52	11.37	0.00	0.00	0.00	0.18	0.35	敬文
107	DAIS(P)	8.50	1.32 X 1.37	1.20	78.23	21.05	0.00	0.08	0.17	0.00	0.20	0.26	敬□
108	DAIS(P)	4.67	1.20 X 1.17	1.19	67.33	16.56	13.68	0.00	0.36	0.00	0.71	1.36	忠信
109	DAIS(P)	2.16	1.16 X 1.16	0.75	73.99	13.87	9.61	0.00	0.00	0.00	1.36	1.16	中信
110	DAIS(P)	5.59	1.00 X 1.00	1.16	69.20	25.60	4.94	0.00	0.00	0.00	0.26	0.00	慈行
111	DAIS(P)	4.00	1.17 X 1.19	1.15	59.96	26.43	9.96	0.08	0.25	0.00	1.34	1.98	士信
112	DAIS(P)	3.91	0.96 X 0.94	1.03	61.04	24.38	13.39	0.17	0.76	0.00	0.09	0.16	言身
113	DAIS(P)	7.89	1.09 X 1.10	1.28	73.48	20.77	5.59	0.06	0.00	0.00	0.07	0.03	青中
115	DAIS(P)	2.10	0.95 X 0.96	0.66	52.73	25.28	18.44	0.00	1.91	0.00	0.73	0.91	志星
116	DAIS(P)	1.95	0.96 X 0.96	1.00	43.65	23.79	27.76	0.00	0.00	0.00	2.69	2.11	志星
117	DAIS(P)	5.83	1.06 X 1.06	1.13	78.87	21.20	0.00	0.00	0.00	0.00	0.30	0.00	事止
118	DAIS(P)	5.11	1.06 X 1.08	1.25	64.24	26.63	8.08	0.00	0.00	0.00	0.39	0.67	明上
119	DAIS(P)	7.30	1.28 X 1.28	1.12	71.29	14.61	13.65	0.00	0.00	0.00	0.17	0.27	善壽
120	DAIS(P)	8.32	1.30 X 1.26	1.18	63.39	12.78	20.78	0.08	2.51	0.00	0.20	0.26	善壽
121	DAIS(P)	6.37	1.25 X 1.25	1.05	64.95	18.70	15.54	0.00	0.00	0.00	0.30	0.80	善壽
122	DAIS(P)	2.11	1.05 X 1.05	0.80	83.80	13.05	0.00	0.00	0.00	0.00	1.64	1.51	易壽
123	DAIS(P)	6.31	1.21 X 1.21	1.28	86.53	10.19	0.00	0.24	0.87	0.00	0.82	1.34	長生
125	DAIS(P)	4.79	1.19 X 1.20	1.24	57.08	6.78	34.24	0.13	1.05	0.00	0.28	0.44	生□
126	DAIS(P)	3.08	1.06 X 1.06	0.97	59.56	15.93	23.10	0.15	0.00	0.00	0.66	0.59	萬金
127	DAIS(P)	4.95	1.30 X 1.32	1.27	53.73	4.90	38.41	0.00	1.28	0.00	0.83	0.83	千万
128	DAIS(P)	5.09	1.15 X 1.13	1.28	64.09	11.35	21.66	0.00	0.00	0.00	1.08	1.82	大吉
130	DAIS(P)	9.64	1.25 X 1.25	1.30	57.50	10.77	30.88	0.17	0.46	0.00	0.11	0.12	私鉨
131	DAIS(P)	4.88	1.05 X 0.97	1.20	71.94	22.73	4.05	0.00	0.88	0.00	0.36	0.03	私鉨
132	DAIS(P)	6.80	(1.21)	1.14	67.11	10.28	21.07	0.00	1.42	0.00	0.09	0.03	敬上
133	DAIS(P)	2.34	(1.07)	1.06	45.81	32.16	20.32	0.00	0.00	0.00	1.71	0.00	士行
134	DAIS(P)	2.71	(1.20)	0.80	77.18	22.3	0.00	0.00	0.00	0.00	0.48	0.00	中身
135	DAIS(P)	4.09	(1.11)	0.94	49.65	11.96	37.82	0.00	0.00	0.00	0.57	0.00	敬中
136	DAIS(P)	1.91	(1.06)	0.89	77.22	22.20	0.00	0.00	0.00	0.00	0.57	0.00	敬中
137	DAIS(P)	6.90	(1.25)	1.35	65.51	14.75	19.58	0.10	0.00	0.00	0.06	0.00	明上
138	ANIMAL(P)	9.79	(2.35)	2.05	66.31	18.34	12.51	0.00	2.53	0.00	0.24	0.03	□臣
139	NOSE(P)	3.12	1.90 X 1.55	0.86	67.47	22.04	5.10	5.23	0.00	0.00	0.16	0.00	士君子
140	DAIS(P)	6.85	1.17 X 1.14	1.37	57.08	12.00	29.68	0.13	0.34	0.00	0.26	0.50	又千白萬
141	DAIS(P)	8.44	1.56 X 1.52	0.96	73.04	9.92	16.39	0.15	0.31	0.00	0.07	0.12	可以正下
142	PAVILION(P)	11.60	1.55 X 1.55	1.39	67.76	6.60	25.08	0.04	0.14	0.00	0.31	0.08	至□□□
143	NOSE(P)	5.70	1.03 X 1.05	0.76	63.60	9.85	26.27	0.20	0.00	0.00	0.05	0.03	德
144	NOSE(P)	1.34	0.76 X 0.77	0.55	58.63	15.78	24.44	0.00	1.05	0.00	0.10	0.00	我
145	NOSE(P)	4.30	1.40 X 1.50	0.64	63.77	14.73	20.24	0.09	0.84	0.00	0.18	0.14	丘
146	NOSE(P)	4.06	1.33 X 1.33	0.87	57.94	10.84	30.17	0.15	0.33	0.00	0.03	0.52	室
147	NOSE(P)	4.71	1.33 X 1.30	0.78	73.84	7.44	18.20	0.05	0.38	0.00	0.03	0.06	昌
148	NOSE(P)	1.90	0.94 X 0.94	0.50	80.15	13.25	5.11	0.00	1.43	0.00	0.07	0.00	笔
149	NOSE(P)	5.64	1.26 X 1.23	0.72	63.93	4.51	31.10	0.06	0.36	0.00	0.04	0.00	生
150	NOSE(P)	7.30	1.55 X 1.21	1.63	76.73	15.67	6.52	0.32	0.49	0.00	0.26	0.00	王
151	NOSE(P)	4.37	1.05 X 1.10	0.77	71.54	3.48	18.81	0.26	0.40	5.31	0.21	0.00	尚
152	NOSE(P)	6.77	(1.58)	0.84	68.86	7.81	23.08	0.06	0.13	0.00	0.02	0.04	尚
153	NOSE(P)	4.11	(1.25)	0.94	56.78	13.78	28.70	0.13	0.46	0.00	0.11	0.08	傳
154	NOSE(P)	4.74	(1.23)	0.93	61.10	12.83	24.96	0.21	0.82	0.00	0.07	0.00	傳

155	NOSE(P)	7.65	(1.80)	1.00	60.57	19.48	19.67	0.08	0.14	0.00	0.04	0.00	東
156	NOSE(P)	4.60	(0.98)	1.21	61.54	21.29	16.78	0.11	0.27	0.00	0.00	0.00	文
157	NOSE(P)	0.81	(0.73)	0.72	48.09	48.19	0.00	0.46	1.88	0.00	1.38	0.00	吉
158	NOSE(P)	8.30	(0.91)	0.78	57.93	11.59	30.28	0.11	0.00	0.00	0.07	0.03	昌
159	DAIS(P)	2.60	1.28 X 1.21	1.15	75.15	20.18	0.00	0.00	0.00	0.00	2.44	2.23	敬
160	DAIS(P)	8.44	1.20 X 1.20	0.89	69.21	20.44	9.58	0.16	0.00	0.00	0.26	0.34	敬
161	DAIS(P)	6.88	1.34 X 1.34	1.34	65.98	14.64	19.07	0.22	0.00	0.00	0.05	0.04	敬
162	DAIS(P)	5.41	1.30 X 1.27	1.07	71.16	15.83	12.85	0.11	0.00	0.00	0.05	0.00	敬
163	DAIS(P)	5.55	1.08 X 1.02	1.13	76.62	10.43	12.37	0.00	0.44	0.00	0.08	0.06	慈
164	DAIS(P)	2.80	1.10 X 1.10	1.04	75.16	23.43	0.00	0.19	0.86	0.18	0.19	0.00	信
165	DAIS(P)	3.38	0.90 X 0.90	0.83	58.13	24.19	17.30	0.22	0.00	0.00	0.13	0.02	尚
166	DAIS(P)	4.34	0.96 X 0.93	1.00	64.40	31.58	3.26	0.13	0.17	0.00	0.42	0.04	尚
167	DAIS(P)	5.16	0.96 X 0.97	1.12	63.12	15.20	21.43	0.08	0.00	0.00	0.11	0.06	尚
168	DAIS(P)	5.84	1.17 X 1.14	0.79	65.17	13.82	20.75	0.22	0.00	0.00	0.04	0.00	尚
169	DAIS(P)	3.98	1.20 X 1.20	0.99	74.33	11.74	13.19	0.13	0.55	0.00	0.07	0.00	正
170	DAIS(P)	6.77	1.00 X 1.00	0.94	65.29	18.84	15.39	0.00	0.32	0.00	0.14	0.02	口
171	DAIS(P)	5.56	1.14 X 1.14	1.14	63.20	11.42	23.52	0.08	0.32	0.00	0.50	0.97	生
172	DAIS(P)	2.85	1.08 X 1.16	1.27	64.32	26.99	8.57	0.00	0.00	0.00	0.13	0.00	昌
173	DAIS(P)	4.11	0.91 X 0.91	1.09	22.11	14.24	63.58	0.00	0.00	0.00	0.04	0.03	文
174	DAIS(P)	0.97	1.02 X 1.05	0.92	8.23	54.69	33.90	0.00	0.00	0.00	1.56	1.62	成
175	DAIS(P)	7.00	0.72 X 0.72	0.74	81.04	14.56	3.80	0.10	0.27	0.00	0.23	0.00	万
176	DAIS(P)	3.73	1.37 X 1.37	1.13	76.30	22.69	0.00	0.00	0.00	0.00	0.39	0.63	万
177	DAIS(P)	5.41	1.06 X 1.07	1.07	62.73	12.17	24.32	0.00	0.00	0.00	0.77	0.00	驊
178	DAIS(P)	3.86	1.24 X 1.24	1.16	73.07	14.98	11.79	0.00	0.00	0.00	0.06	0.09	尔
179	DAIS(P)	4.86	1.26 X 1.24	0.89	55.39	11.70	31.88	0.12	0.46	0.00	0.36	0.08	琳
181	DAIS(P)	4.94	(1.01)	0.86	67.10	14.32	18.52	0.00	0.00	0.00	0.03	0.04	慈
182	DAIS(P)	4.60	(1.27)	0.96	61.23	11.99	26.34	0.00	0.35	0.00	0.08	0.00	安
183	DAIS(P)	10.68	(1.25)	1.04	67.08	16.69	16.01	0.06	0.00	0.00	0.13	0.04	生
184	DAIS(P)	6.99	(1.66)	1.20	83.12	2.58	13.76	0.00	0.53	0.00	0.00	0.00	生
185	DAIS(P)	5.73	(1.00)	1.70	57.45	10.01	29.24	0.13	0.48	0.00	0.93	1.76	譽
186	DAIS(P)	6.07	(1.41)	1.30	73.35	13.83	12.65	0.09	0.00	0.00	0.04	0.04	吉
187	DAIS(P)	7.03	(1.16)	1.10	61.30	14.53	23.78	0.16	0.00	0.00	0.16	0.06	山
188	DAIS(P)	4.99	(1.21)	1.25	64.67	9.18	24.97	0.17	0.89	0.00	0.05	0.07	琳
189	PAVILION(P)	10.11	1.34 X 1.34	1.25	62.80	16.15	19.63	0.15	0.95	0.00	0.18	0.14	昌
190	PAVILION(P)	7.09	1.16 X 1.15	2.24	58.24	6.91	33.39	0.16	0.70	0.00	0.12	0.49	吉
191	PAVILION(P)	6.54	1.25 X 1.25	1.36	59.15	4.63	35.19	0.11	0.74	0.00	0.07	0.11	吉
192	PAVILION(P)	6.60	1.09 X 1.09	1.95	71.46	18.57	9.39	0.04	0.15	0.00	0.14	0.24	万
193	ANIMAL(P)	11.93	1.90 X 1.04	1.29	67.00	6.32	26.43	0.06	0.18	0.00	0.02	0.00	火
194	THREAD(P)	1.89	3.21 X 1.35	1.52	68.25	25.28	6.12	0.00	0.00	0.00	0.34	0.00	共
195	NOSE(P)	2.78	(1.32)	0.66	64.67	16.93	17.95	0.21	0.00	0.00	0.12	0.12	双獸紋
196	NOSE(P)	11.41	(2.30)	0.89	67.24	12.95	19.74	0.04	0.00	0.00	0.03	0.00	双鹿紋
197	NOSE(P)	5.86	(1.87)	0.89	72.01	9.75	18.22	0.00	0.00	0.00	0.02	0.00	双獸紋
198	NOSE(P)	3.90	(1.55)	0.86	68.40	20.50	10.18	0.28	0.43	0.00	0.09	0.11	鳥紋
199	NOSE(P)	14.18	(2.00)	1.08	61.66	9.72	28.20	0.10	0.28	0.00	0.02	0.02	獸紋
200	NOSE(P)	7.13	(2.00)	0.63	67.42	18.71	13.07	0.00	0.50	0.00	0.29	0.00	獸紋
201	NOSE(P)	7.88	(2.03)	0.98	68.08	16.67	14.64	0.16	0.31	0.00	0.09	0.06	蝙蝠紋
202	NOSE(P)	4.58	1.45 X 1.45	1.06	79.27	20.66	0.00	0.00	0.00	0.00	0.07	0.00	人獸紋
203	DAIS(P)	28.52	2.96 X 2.91	1.50	77.31	10.48	10.27	0.26	0.57	0.00	1.12	0.00	獸面紋
204	POST(P)	11.75	2.05 X 1.53	1.69	70.27	8.63	20.46	0.16	0.24	0.22	0.02	0.00	鳥紋

Time period of origin: **Han** 206 BC – 220 AD
Southern and Northern 420 - 589 AD

Dynasty. Number of seals: 46 (P): Private (O): Official

Average percentage content:		
	Cu	66.00 ± 15.93
	Sn	18.26 ± 13.99
	Pb	14.23 ± 9.86
	Fe	0.52 ± 0.69
	Sb	0.39 ± 0.36
	As	0.45 ± 0.35
	Zn	0.04 ± 0.02
	Mg	0.11 ± 0.18

CODE	TYPE BUTTON	WEIGHT (gm)	CIRCUMFERENCE OR (DIAMETER) (cm)	HEIGHT (cm)	CONTENT (%)								INSCRIPTION
					CU	SN	PB	SB	AS	ZN	FE	MG	
205	NOSE(O)	93.08	2.42 X 2.42	2.12	89.08	3.46	6.30	0.28	0.03	0.00	0.58	0.00	騎部曲將
206	TILE(O)	93.08	2.56 X 2.53	2.46	88.02	3.72	6.96	0.34	0.37	0.00	0.60	0.00	軍司馬印
207	TORTOISE(O)	68.37	2.26 X 2.40	2.80	76.22	4.09	16.75	0.44	0.94	1.42	0.13	0.00	撫南司馬
208	NOSE(P)	2.23	0.85 X 0.87	0.65	61.88	26.88	11.10	0.00	0.00	0.00	0.14	0.00	左 樗
209	NOSE(P)	3.22	0.92 X 0.96	0.76	79.74	10.77	8.93	0.15	0.00	0.00	0.41	0.00	李 淩
210	NOSE(P)	4.33	1.07 X 1.07	0.84	71.89	22.98	4.96	0.00	0.00	0.00	0.13	0.04	憤 悼
211	NOSE(P)	4.94	1.22 X 1.22	0.80	26.32	7.54	66.00	0.07	0.00	0.00	0.14	0.02	程 夫
212	NOSE(P)	2.50	0.95 X 0.95	0.73	67.51	20.26	10.75	0.00	0.85	0.00	0.42	0.23	射 積
213	NOSE(P)	5.57	1.20 X 1.20	0.50	82.97	4.78	11.17	0.51	0.56	0.00	0.04	0.00	梁遂成
214	NOSE(P)	5.91	1.43 X 1.42	1.15	77.85	8.09	11.52	0.47	0.55	0.00	0.90	0.63	康昌私印
215	NOSE(P)	8.92	1.22 X 1.18	1.22	66.77	14.35	17.67	0.39	0.63	0.00	0.19	0.00	周廣私印
216	NOSE(P)	3.67	1.11 X 1.06	0.72	76.85	11.87	10.65	0.42	0.00	0.00	0.17	0.05	韋
217	DAIS(P)	4.47	1.17 X 1.14	0.90	14.98	66.81	17.97	0.03	0.00	0.00	0.18	0.03	號 野
218	DAIS(P)	4.50	1.21 X 1.21	1.03	54.03	18.70	26.12	0.00	0.62	0.00	0.29	0.23	徐 成
219	DAIS(P)	1.56	0.76 X 0.76	0.70	73.33	24.12	0.00	0.56	1.32	0.00	0.68	0.00	任 勝
220	DAIS(P)	3.24	0.96 X 0.96	0.85	63.63	27.96	7.73	0.09	0.00	0.00	0.41	0.17	陳 口
221	DAIS(P)	3.79	1.05 X 1.07	0.80	65.40	5.59	28.28	0.16	0.54	0.00	0.03	0.00	曾 可
222	DAIS(P)	10.67	1.50 X 1.50	1.15	82.81	2.95	14.49	0.44	0.52	0.00	0.79	0.00	壽 慶
223	DAIS(P)	7.08	1.39 X 1.35	1.04	78.27	8.38	12.77	0.19	0.29	0.00	0.11	0.00	盅
225	TILE(P)	22.21	1.75 X 1.75	1.56	73.14	7.76	17.96	0.29	0.35	0.00	0.48	0.00	范弘之印
226	TILE(P)	15.3.	1.73 X 1.67	1.34	74.35	8.97	15.94	0.33	0.32	0.00	0.04	0.04	聶定私印
228	TILE(P)	47.45	1.90 X 1.98	1.82	67.13	16.26	15.26	0.23	0.44	0.00	0.29	0.37	蘇忠私印
229	BRIDGE(P)	10.28	1 54 X 1.48	1.73	68.41	22.47	8.19	0.46	0.43	0.00	0.05	0.00	傅賀之印
230	BRIDGE(P)	7.16	1 52 X 1.55	1.27	61.49	27.03	9.64	0.54	0.28	0.00	0.63	0.39	徐延信印
231	BRIDGE(P)	5.17	1.23 X 1.23	1.09	71.95	15.73	10.19	0.00	0.00	0.00	1.63	0.50	劉可之印
232	BRIDGE(P)	6.35	1.56 X 1.59	1.34	59.57	30.80,	7.53	0.39	0.33	0.00	1.22	0.16	秦陽信印
233	TORTOISE(P)	9.90	1.22 X 1.26	1.35	73.40	7.09	18.60	0.43	0.41	0.00	0.07	0.00	王陽私印
234	TORTIOSE(P)	10.77	1.26 X 1.20	1.45	74.60	11.17	13.27	0.56	0.33	0.00	0.05	0.02	朱 義
236	TORTOISE(P)	10.25	1.23 X 1.26	1.45	69.74	10.84	18.35	0.38	0.39	0.00	0.25	0.05	雷衡私印
237	TORTOISE(P)	8.20	1.44 X 1.38	1.22	71.05	22.48	4.62	0.40	0.52	0.00	0.42	0.53	郭植私印
238	ANIMAL(P)	5.33	0.79 X 0.62	1.57	66.88	4.99	27.25	0.24	0.56	0.00	0.09	0.00	左 公
239	ANIMAL(P)	3.17	1.77 X 1.72	1.54	84.37	6.43	6.92	0.51	0.53	0.00	0.56	0.68	司馬衛森
241	HOLE(P)	13.22	1.35 X 1.35	2.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	司馬緒印 白記
242	HOLE(P)	4.67	1.32 X 1.32	0.46	61.42	24.70	13.21	0.21	0.18	0.00	0.24	0.05	朱中 朱衰日
243	HOLE(P)	4.34	1.38 X 1.38	0.55	56.03	23.64	19.09	0.19	0.26	0.00	0.79	0.00	朱孟 朱燕
244	HOLE(P)	7.79	1.85 X 1.80	0.78	56.84	29.70	9.78	0.99	1.02	0.00	1.43	0.24	李丞信印 李子威印
245	HOLE(P)	5.73	1.23 X 1.24	0.63	70.07	19.12	8.82	0.11	1.17	0.22	0.45	0.03	尚德 尚孝

246	HOLE(P)	2.09	1.16 X 1.15	0.97	26.65	50.13	20.55	1.98	0.00	0.00	0.63	0.06	[illegible]
247	HOLE(P)	3.37	1.20 X 1.20	0.51	42.84	39.19	14.21	1.16	0.77	0.00	1.68	0.14	陳新 巨新
248	HOLE(P)	5.47	1.44 X 1.44	0.61	62.66	29.79	6.15	0.58	0.60	0.00	0.16	0.07	陳陽 陳叔文
249	HOLE(P)	6.21	1.84 X 1.82	0.68	67.02	12.75	14.20	0.87	0.81	0.00	4.24	0.10	[illegible]
250	HOLE(P)	3.48	1.40 X 1.42	0.55	57.23	24.55	16.82	0.16	0.59	0.00	0.61	0.05	郭新之印 郭卿之印
251	HOLE(P)	3.51	1.47 X 1.50	0.56	42.05	43.24	12.54	0.86	1.04	0.00	0.17	0.09	[illegible]
252	HOLE(P)	5.20	1.61 X 0.98	0.58	68.93	20.25	10.30	0.12	0.00	0.00	0.35	0.04	蔡陽 巨陽
253	HOLE(P)	11.28	1.19 X 1.11	0.59	80.51	4.45	13.63	0.45	0.64	0.00	0.32	0.00	[illegible]
254	HOLE(P)	7.08	1.68 X 1.70	0.62	41.33	43.91	12.62	0.67	0.89	0.00	0.54	0.04	[illegible]之印 文口之印

Time period of origin: T'ang 618 – 906 AD
Hing 1368 – 1644 AD Dynasty.

Number of seals: 10 (P): Private (O): Official

Average percentage content:

Cu	70.40 ± 7.17
Sn	10.43 ± 3.90
Pb	18.05 ± 6.70
Fe	0.33 ± 0.41
Sb	0.16 ± 0.14
As	0.37 ± 0.15
Zn	0.11 ± 0.25
Mg	0.11 ± 0.22

CODE	TYPE	WEIGHT	CIRCUMFERENCE OR DIAMETER)	HEIGHT			CONTENT (%)						
	BUTTON	(gm)	(cm)	(cm)	CU	SN	PB	SB	AS	ZN	FE	MG	INSCRIPTION
256	NOSE(P)	5.14	2.13 X 1.93	1.01	58.58	10.39	29.02	0.00	0.65	0.00	0.68	0.69	天下太平
257	NOSE(P)	5.30	1.50 X 1.45	0.89	67.92	9.75	21.11	0.09	0.25	0.76	0.07	0.05	花押
259	NOSE(P)	8.66	2.37 X 2.03	1.57	75.69	7.54	16.16	0.13	0.42	0.00	0.03	0.03	花押
260	POST(P)	26.56	2.94 X 1.27	2.95	80.35	13.19	4.63	0.51	0.46	0.00	0.83	0.02	[illegible]字花押
261	POST(P)	10.28	1.44 X 0.88	2.85	63.85	19.51	16.18	0.13	0.32	0.00	0.01	0.00	八思巴文花押
262	POST(P)	32.15	2.20 X 1.18	2.24	66.22	9.58	22.88	0.14	0.14	0.00	1.04	0.00	口新花押
266	COUPLE(P)	9.73	1.66 X 1.00	2.43	73.89	8.52	16.82	0.14	0.34	0.00	0.15	0.16	八思巴文花押
267	RING(P)	15.41	1.79 X 1.87	0.96	68.78	9.48	20.83	0.15	0.49	0.24	0.00	0.02	八思巴文花押
269	ANIMAL(P)	24.80	2.20 X 2.30	2.68	78.39	6.21	14.78	0.18	0.29	0.00	0.15	0.00	[illegible]

Remark: Code numbers 42, 52 ,173, 174, 211 and 217 were excluded in the calculations for the overall average percentage content of the major constituents of ancient Chinese bronze.

Robert Bakewell 1682-1752

Roger Wood

1982 finds the City of Derby celebrating the tricentenary of the birth of Robert Bakewell, famous gatesmith.

Little is known of Bakewell's early life. He was baptised at the Parish Church of Uttoxeter, Staffordshire on March 5th, 1682. Blacksmithing seems to have been in Robert's blood because both his father Samson and grandfather John Sales, were smiths.

Samson Bakewell died in 1695 leaving his wife Mary to cope with 4 children. Robert now 13 was apprenticed out to learn his trade.

In 1706 Bakewell was found working for Rt Hon Thomas Coke MP, Vice Chamberlain to the court of Queen Anne and King George I.

Coke, an amateur architect and garden designer, required a centre-piece for his newly-laid garden at Melbourne Hall, Derbyshire; he chose Robert to make an elaborate iron arbour (summerhouse).

Bakewell set up his forge at the Stone House at Melbourne, the home of widow Fisher and her five daughters. (This has recently been rediscovered, complete with stone quenching bosh).

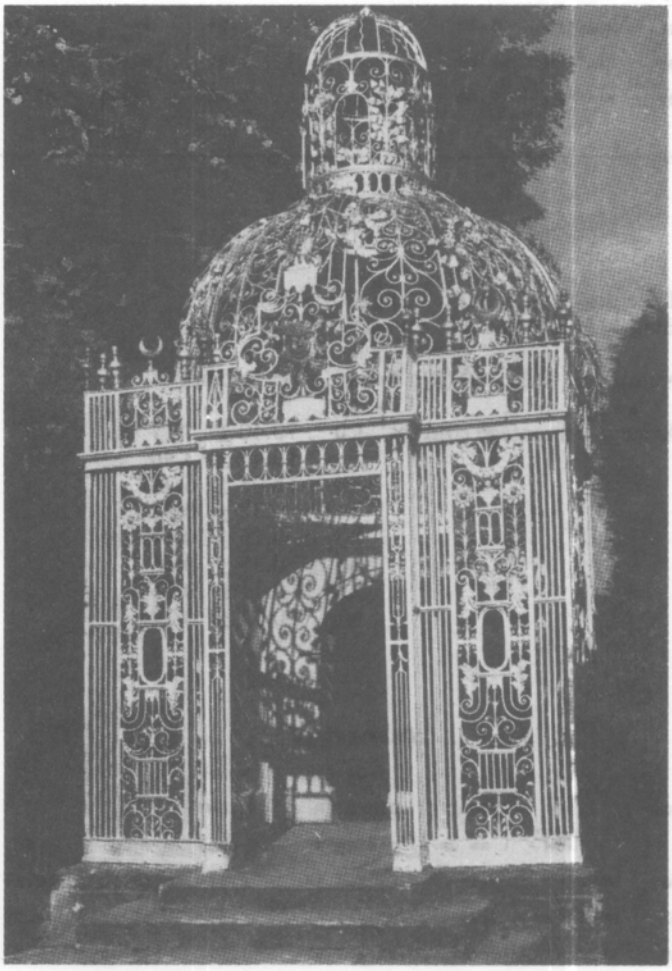
Due to illness the completed arbour was not erected until 1708.

Shortly after completing the Melbourne contract Bakewell set up a forge in the parish of St Peters, Derby. He remained here for 30 years making decorative ironwork for many large houses and churches.

Benjamin Yates worked with Bakewell and completed some contracts after Robert's death in 1752.

A few examples of Robert Bakewell's fine work can be seen:

Arbour, Melbourne Hall, Derbyshire.
Altar Rail, St Saviour's Church, Foremark, Derbyshire.
Silkmill Gates, Industrial Museum, Derby.
Altar Rail, St Stephen's Church, Borrowash, Derbyshire.
Balustrade, Homestead House, Spondon, Derbyshire.
Altar Rail, Gates and other internal fittings, All Saints Church, Cathedral, Derby.
Font Cover, St Werburgh's Church, Derby.
Gates, Newnham Paddox, Warwickshire.
Gates, Oke Over Hall, Staffordshire.
Balcony Rails and Gates, Aldenham Park, Bridgnorth, Shropshire.
Gates (Hospital), Preston-upon-the-Weald, Shropshire.
Staircase and other fittings, Staunton Harold House, (Cheshire Home), Leicestershire. (Made by Yates to a copy of an original design by Bakewell after house modifications).
Altar Rail, Staunton Harold Church, Leicestershire.



Melbourne Hall Garden Arbour by Robert Bakewell

Celebrations at Derby started with an exhibition of Bakewell's work on show in the City Museum, opened by the Marquess of Lothian of Melbourne Hall, on February 27th.

Two illustrated lectures were also given, the first by Edward Saunders on March 5th, described in detail Bakewell's life and work.

The second entitled 'The Art of Wrought Ironwork' given by Alan Knight FSDC on March 11th, gave details of Mr Knight's own life and apprenticeship.

Mr Knight is almost unique because he still uses wrought iron and not mild steel for forging. His stocks of wrought iron were obtained by Walmsleys of Bolton before their recent closure. Most of his work today comprises restoring old gates and wrought artifacts by the early masters. Splendid examples of iron carnations, orchids, vines laden with grapes, thistle heads etc were shown to an appreciative audience. These had all been made at his Worcester Forge.

The Saint-Maurice Ironworks, Canada

Pierre Beaudet

The Saint-Maurice ironworks was a centre of industrial activity from 1733 to 1883. It most probably was the only site in French North America prior to 1760 where iron ore was transformed into cast and wrought iron products.

Now a National Historic Park, the multi-terraced site is situated a few miles north of the city of Three-Rivers, or approximately half-way between Quebec City and Montreal. It is administered by Parks Canada, an agency of the Department of the Environment.

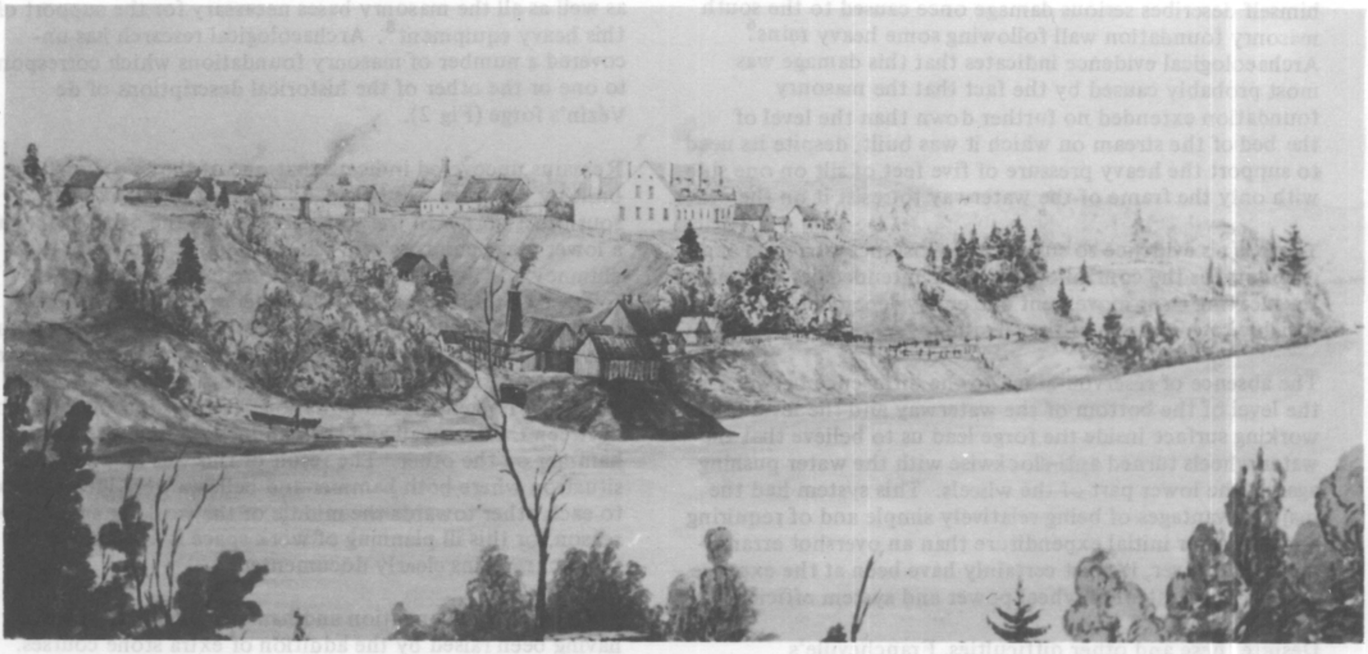
The first archaeological excavations took place on the ironworks' site in the mid-1960s while major systematic archaeological and historical research programs have been pursued by Parks Canada since 1973.

The object of this paper is not to relate in detail the history of the ironworks nor to describe the various elements of its integrated industrial complex. Rather, it is to focus attention on some of the difficulties encountered in acquiring technical know-how and in adapting it to a new and somewhat difficult environment in the area known as the Lower Forge.

The first industrial implantation occurred in 1733 under the direction of Francois Poulin de Francheville, a Montreal merchant and absentee owner of the site[1]. On his property were to be found an abundance of bog iron ore and wood for construction and the making of charcoal fuel. Water power was also available through the harnessing of the **ruisseau du Lavoir** on whose banks there was space for the building of a mill. The nearby Saint-Maurice river offered navigable waters which connected directly to the Saint-Lawrence and hence to local and French markets. Francheville appeared to have all the natural requirements necessary for the setting up of a successful ironworks. However, Francheville was a merchant with little knowledge of ironworking nor, for that matter, of the particularities or the idiosyncrasies of the environment of his chosen site.

Relatively little is known of the ironworks built by Francheville. Historical documentation is scarce and period iconography nonexistent. However, some information is available. For instance, it is known that Francheville had built the equipment necessary for the direct reduction of bog iron ore which involved the heating of the iron ore into a pasty mass which could then be hammered into bar shapes of various sizes. Francheville's forge included, according to historical sources, a hammer and a masonry hearth similar to that found in a blacksmith's forge. Two hydraulic wheels gave motion to the hammer and to the bellows of the hearth[2].

Francheville adopted the use of the direct reduction process, but it was not as a result of his metallurgical knowledge since he had none. Rather, he was obliged to borrow an appropriate technology where most convenient. To this end, he sent three workers with some experience in blacksmithing to New England to gather plans for the building of a forge and information on its operation. The exact destination of Francheville's emissaries is not known, but it most probably was Massachussets where an ironworking industry already existed. In Massachussets, Francheville's workers could have observed the working of iron both with the direct and indirect methods of reduction. The indirect method of reduction with separate blast furnace and forge required a major investment of money and a thorough knowledge of a complex series of procedures while direct reduction or a bloomery involved much lower building costs and the mastering of relatively simpler procedures. Technical simplicity and lower costs were probably the two major factors which brought Francheville to choose the direct



'Mr Bell's Forges on the St Maurice, near 3 Rivers, reduction method for the transformation of iron ore to wrought iron. However, even this method was found to be too complex for ill-qualified workers working with poorly built equipment.

Historical sources reveal some of the difficulties which faced Francheville's workers. According to one of the workers, the emissaries had been in New England too short a time to learn exactly how to smelt the ore and the conditions necessary in the hearth to achieve proper results[3]. It is thus somewhat haphazardly that Francheville's workers managed to produce two thousand pounds of wrought iron bars in 1734, which was the only period of regular activity for the first forge built on the site[4].

Archaeological excavations have uncovered only a few remains of the forge built by Francheville. These include remains of the south and west masonry foundation walls as well as a number of jointed wooden beams which served most probably as the frame for the waterwheels' launder. These remains are hardly sufficient to allow a more than theoretical reconstruction of the forge especially in the absence of any trace of frame, hearth, tools or heavy equipment. However, in replacing the few archaeological remains uncovered in their stratigraphical context it is possible to better understand the difficulties that faced the builders and workers of Francheville's forge.

The role of foundations is to establish equilibrium or a stable relationship between a building above ground and the ground on which it rests. It is therefore important to make sure that the natural support be sufficient to withstand the pressure of the building that rests upon it. Precautions usually taken include building foundations to a depth sufficient to resist sinking or the erosive effects of running surface waters and frost. The importance of these precautions is even more evident when one considers that the ground on which the forge was built was described as being as moving and flowing as a bridge made of rope in such a way that pressure applied in one spot resulted in ripples everywhere else[5]

It is far from certain that the builders of Francheville's forge took the necessary precautions to protect their structure from the local environment and, in particular, unstable soil conditions, heavy ground water run-off and heavy heaving caused by freezing. In fact, Francheville himself describes serious damage once caused to the south masonry foundation wall following some heavy rains[6]. Archaeological evidence indicates that this damage was most probably caused by the fact that the masonry foundation extended no further down than the level of the bed of the stream on which it was built, despite its need to support the heavy pressure of five feet of silt on one side with only the frame of the waterway to resist it on the other.

There is no evidence to suggest the existence of a dam and reservoir for the control of the water intended for the wheels thus leaving their movement extremely dependent on the variable rate of flow of the stream.

The absence of reservoir allied to the difference between the level of the bottom of the waterway and the level of the working surface inside the forge lead us to believe that the water wheels turned anti-clockwise with the water pushing against the lower part of the wheels. This system had the major advantages of being relatively simple and of requiring a much lower initial expenditure than an overshot arrangement. However, it must certainly have been at the expense of a proper control of wheel power and system efficiency.

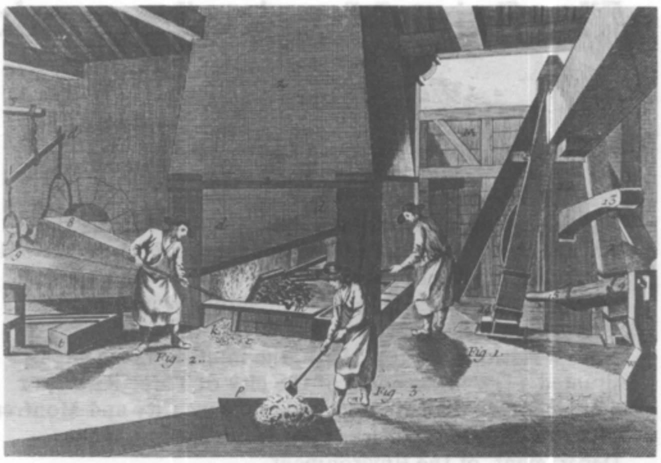


Fig 1

Despite these and other difficulties, Francheville's endeavours at least proved that it was possible to produce wrought iron with the resources of the site. However, it was to be left to his successors to build a profitable enterprise through the adoption of a more complex technology and more efficient equipment.

The forge built by Francheville was demolished either in 1734 or 1735. A year later, a company headed by Olivier de Vézin built a new industrial complex with separate blast furnace and forge for the production of both cast and wrought iron products. Olivier de Vézin was a forge master brought especially from France to build a profitable ironworks. He did not have to borrow a technology from New England but was able to adapt the knowledge he had acquired in France to a different environment. Further, de Vézin had at his disposal the necessary financial backing to build the structures and the equipment necessary for the operation of an ironworks with the indirect reduction process, much as found in France at that time and described in Diderot's Encyclopaedia[7] (Fig 1). De Vezin could thus apparently count on the natural advantages of the site, his technical know-how and the necessary funds to help him succeed in his enterprise.

According to a 1741 inventory, the lower forge originally built by de Vezin included for the working of iron, two hearths with their bellows, a belly helve hammer, an anvil as well as all the masonry bases necessary for the support of this heavy equipment[8]. Archaeological research has uncovered a number of masonry foundations which correspond to one or the other of the historical descriptions of de Vézin's forge (Fig 2).

Remains uncovered indicate that one of the two chimneys built by de Vézin was originally situated in the extreme south-east corner of the work area, while the other rose where a lower forge chimney still stands (Fig 3). The south-east chimney was definitely set too close to the corner of the forge to allow for proper arrangement of the work area. Both archaeological and historical evidence clearly attest to this very impractical initial arrangement which was corrected by the construction of another chimney in 1743[9]. The original arrangement did not allow for the situating of bellows between the east wall and the chimney on one side and the hammer on the other. The result of this was an awkward situation where both hammer and bellows were located next to each other towards the middle of the working area. The reason for this ill planning of work space is not known but the fact remains clearly documented.

Both chimney foundation and hammer base bear signs of having been raised by the addition of extra stone courses.

Remains of the indirect reduction forge built by de Vézin (1736 - late 18th century).

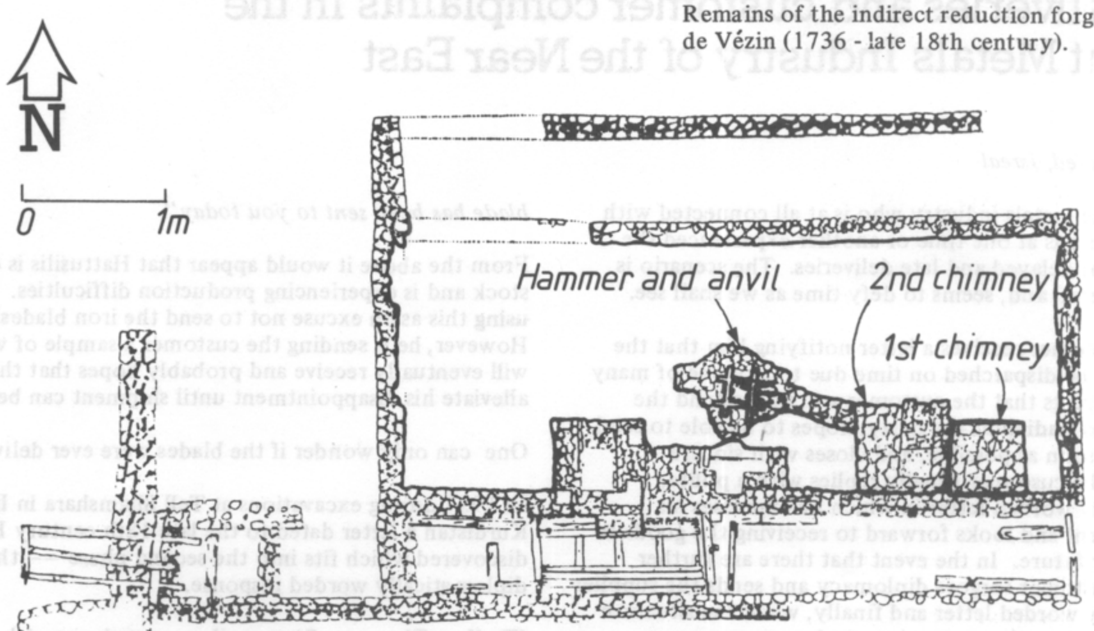


Fig 2

These masonry foundations were most probably raised at the same time as the entire surfaces of the work and storage areas in order to counter recurrent spring flooding. It is within one of these land fills that a unique collection of finished and semi-finished products of the forge were recovered.

Other environmental and technical problems plagued the lower forge built by de Vézin. Of these, let me only mention the choice of improper species of wood for the building of some of the heavy equipment and the need, despite a reservoir and dam, to adapt the entire annual work cycle to the succession of prolonged winter freezing, heavy spring run-off and relatively dry summers.

All these factors must have contributed to the failure of de Vézin and his associates to create a profitable enterprise before the take-over of the ironworks by the French Crown.

In conclusion it appears that the forge built by Francheville was not the product of French metallurgical tradition but in great part the poorly assimilated borrowing of a process observed in New England. His failure was mostly the result of a lack of know-how and of a poor understanding of the particularities of the local environment. On the other hand, de Vézin's industrial complex would have been built for the most part as a French forge but not without serious growing pains resulting from a number of technical and environmental problems which were in great part the result of the lack of practical knowledge of a difficult environment.

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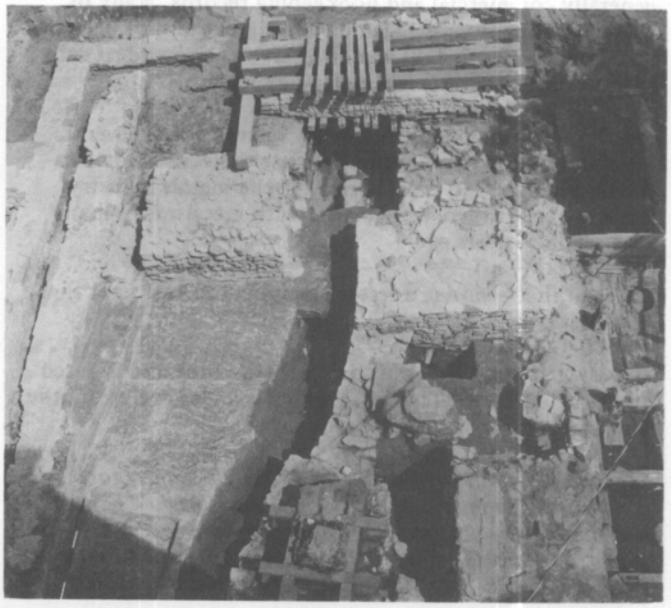

Fig 3

Late deliveries and customer complaints in the Ancient Metals Industry of the Near East

Eli Minoff, Safed, Isreal

Anyone in the metals industry who is at all connected with placing orders has at one time or another experienced the frustrations of delayed and late deliveries. The scenario is typical, universal and, seems to defy time as we shall see.

First, the customer receives a letter notifying him that the order cannot be dispatched on time due to any one of many reasons and trusts that the customer will understand the circumstances leading to the delay, hopes to be able to send the goods as soon as possible, and closes with sincere apologies. The customer usually replies with a polite, diplomatically worded letter in which he expresses his disappointment and looks forward to receiving the goods in the very near future. In the event that there are further delays the customer forgoes diplomacy and sends the supplier a more firmly worded letter and finally, when the situation becomes desperate the matter is passed on to someone 'higher up' for action, in hopes of applying pressure in order to obtain the goods which by now are urgently needed.

The reader may be consoled in the knowledge that his problems are exactly the same as were experienced by his counterpart over 3,500 years ago and that aside from the introduction of the computer, the telephone and other modern devices, basically nothing has really changed as the rest of this article will show.

International commerce in the ancient world was very developed and active and trade routes extended from Ireland in the West to India and China in the East. Mesopotamia located as it was, was a crossroads between East and West and the nations that evolved there during the various historical periods were very active in international trade. The Mesopotamian merchants were very thorough and exact in their business relationships and they kept very meticulous records of all their transactions. These were recorded on clay tablets upon which the uniform ideograms were impressed. These almost indestructible tablets have been found by the thousands in excavations all over the near east. In spite of the fact that the majority of these tablets are generally commercial and bookeeping records, many of them are quite interesting and shed a great deal of light on the events of those days and also serve as a record of daily life, proper names, places, metrology, grammar etc.

It is from these ancient 'files' that I have chosen several letters to illustrate my claim that late deliveries are not a modern malaise but have been with the metals industry since the first orders were placed with metalsmiths many thousands of years ago.

We shall first examine a letter notifying the customer that his order will be delayed.

It was written by Hattusilis III, a Hittite king and is dated to about 1275 BC. The letter which is addressed to another king, presumably Assyrian reads as follows:

'As for the good iron which you wrote me about, good iron is not available in my sealhouse in Kizzuwatna. That it is a bad time for producing iron I have written. But they will produce good iron. So far they have not finished but when they have finished I will send it to you. An iron dagger blade has been sent to you today'[1]

From the above it would appear that Hattusilis is out of stock and is experiencing production difficulties. (Or is using this as an excuse not to send the iron blades). However, he is sending the customer a sample of what he will eventually receive and probably hopes that this will alleviate his disappointment until shipment can be made.

One can only wonder if the blades were ever delivered.

In 1957 during excavations at Tell Shamshara in Iraqi Kurdistan a letter dated to the late 18th century BC was discovered which fits into the second phase –– the diplomatically worded response.

'To Ku: Thus says Bisente, 'I requested materials from Kusanarum which he sent: but there is no tin at my disposal. Surely it cannot be your intention to withold the tin which I have earlier requested? And the tin should correspond to the requirements of twenty thousand troops. The tin, as much as I have requested send me quickly so that I may have the weapons manufactured.'[2]

This appears to be a polite dunning letter and Bisente who has an order for producing some sort of weapon, perhaps lances or axes cannot proceed because the tin he ordered – for casting bronze – has not arrived.

Bisentes' problems appear minor when one considers the agonies suffered by the customers of Ea-nasir who was a big copper merchant in Ur during the reign of Rim-Sin of Larsa also during the 18th century BC.

During the excavations at Ur[3] in the 30s Sir Leonard Woolley discovered the house of Ea-nasir and of course his file cabinets were among the items found. It seems that in addition to his main business he also engaged in some side activities – lending money on interest, property speculation and deals in second-hand clothing. All this at the expense of his copper interests. Ea-nasirs' customers have lost their patience as the following letters show:[4]

'To Ea-nasir: thus says Nanni. Now when you had come you spoke saying thus: I will give good ingots to Gimil-Sin; this you said to me when you have come, but you have not done it. You have offered bad ingots to my messenger saying: 'If you will take it, take it, if you will not take it, go away'. Who am I that you are treating me with such contempt? And that between gentlemen such as we are! . . . Repeatedly you have made them return empty handed . . . Because you have treated me with contempt I shall exercise against you my right of selecting the copper.'

Arbituram writes: '. . *Why have you not given the copper? If you do not give it I will call in your pledges'*

Apparently Ea-nasir is not moved as Arbituram writes once again saying among other things:

'. . . *Why have you not given the copper to Nigga-Nanna?'*

Appa asks for his copper *'in order that my heart shall not* *be troubled'* and Imgur-Sin moans *'Do you not know how tired I am'.*

Ea-nasir may have been the first merchant in history to say *'Take it or leave it'* and it is no wonder therefore that he winds up having to sell part of his house and property to his neighbour.

We finally arrive at the final stage – passing the buck to someone higher up. In this case it's the great Babylonian lawgiver King Hammurabi who ruled during the first half of the 18th century BC who writes to one of his key officials:

'To Sin-idinnam say: This saith Hammurabi. You must find abba wood for the metal workers of Dur-gurgurri. The cut wood is to be shipped to Babylon on barges. The trees are to be cut down in the forest. Only green wood shall be sent. Dead trees must not be used. And see that they bring these pieces of abba wood speedily, that the metal workers be not delayed.' [5]

The live wood mentioned in the letter is needed for the manufacture of charcoal – dead wood is unsuitable. One may ask why one of the greatest kings of antiquity had to take the time to write a letter requesting wood. One possible answer is that delivery delays had caused some sort of mini-energy crisis which was threatening to hold up the production of weapons. Then as now such a situation was intolerable and Hammurabi was forced to intervene in order to get the wood delivered.

When the Hebrew sages compiled the Bible[6] they wrote: *Nothing is new under the sun'.* – How right they were!

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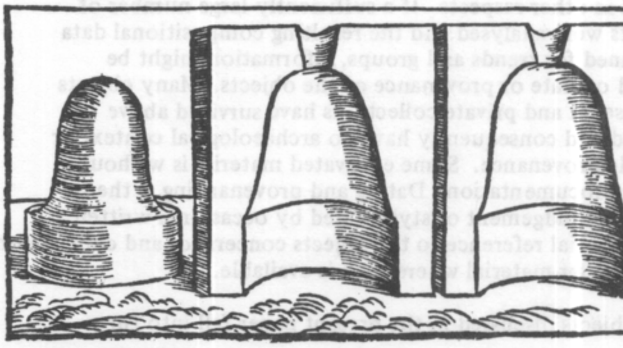
A new bell-founding workshop

During the summer of 1982 an excavation in Paul Street, Exeter, revealed a bell foundry of the late 17th-early 18th century which is believed to be that of the Pennington family who worked in the town from about 1625 to the second decade of the 18th century. The site consists of a very deep ashpit which has the remains of firebars and which certainly fired a reverberatory furnace which has now gone. On the other side of the site of the furnace hearth is the bell-casting pit which has enough room for at least 4 bell moulds. The site is still being excavated and a 5th bell-mould has been found. They appear to have been made vertically with a strickle and there are the remains of much vegetable fibre in the loam of the moulds.

The ash-pit measures 1.0 x 0.5 m in plan and has a surviving depth of about 1.2m with an entry and ash removal hole 0.4 m high under a lintel. The overall length of the passage leading to this is 2.8 m.

The bells were about 0.60 m diameter at the base and one mould still in situ was formed round a ring of half bricks. A considerable quantity of bell metal has been recovered and is being analysed by Dr Paul Craddock.

The site is being excavated by Mr C G Henderson, Director of the Archaeological Field Unit of the Exeter City Council Museums Service, who kindly provided this information.



Mould and core from Pirotechnia by Biringuccio (1540)

Alloy composition of some cast 'latten' objects of the 15|16th centuries

R Brownsword and E E H Pitt

Summary

Analysis by the XRF technique of some 15th-16th century 'latten' candlesticks showed that two groups of compositions were formed based on the relative amounts of copper, lead, zinc and tin in the alloys. The compositional groups corresponded with those established on stylistic grounds, respectively Flemish and English. A number of chafing dishes and hanging lavers of the same period were also analysed and their origins discussed, judged on the basis of the candlestick groups. A measure of success in provenancing was achieved indicating the potential of the approach which is likely to improve as more objects are analysed.

Introduction

When compared with the classical and prehistoric periods, the mediaeval and post-mediaeval period has received less attention from the non-ferrous metallurgist and consequently scientifically established knowledge of the copper-based alloys used by the craftsmen of the period is not extensive. Contemporary writers gave valuable accounts of mediaeval practices both of extraction and alloying and of subsequent fabrication by casting or working but alloy compositions were generally not quoted precisely and unambiguously. Such information related to the main centres of metallurgical activity on the continent and little information exists on English practice.

More recent contributors to archaeological and antiquarian journals have used the terms 'brass', 'bronze' and 'latten' freely to describe the materials under discussion without an agreed basis of understanding of the alloy compositions covered by the terms and in most cases without actual analytical data. Judgement of alloy composition based on colour, the presumed method used for bright finishes, is far from easy with binary copper alloys and is likely to be unreliable for the ternary and quaternary alloys encountered. Heavily patinated or corroded surfaces present impossible situations. Current contributors to journals are more reticent and sometimes make use of the term 'copper-alloy' where no technical information is available but authors of books and articles on early metalwork are often less restrained.

It appeared that a programme of analysis of early copper-alloy objects of relatively humble character would not only increase the body of knowledge on the alloys in general use in the mediaeval and post-mediaeval periods but might be useful in other respects. If a sufficiently large number of objects were analysed and the resulting compositional data examined for trends and groups, information might be gained on date or provenance of the objects. Many objects in museum and private collections have survived above ground and consequently have no archaeological context or reliable provenance. Some excavated material is without proper documentation. Dating and provenancing is then a matter of judgement of style, aided by occasional written and pictorial reference to the objects concerned, and comparison with similar material where such is available.

Fig 1 Chafing dish CV35 (Robin Bellamy Antiques); the handles are not original

The objects discussed in the present paper fall into three groups. The first group is of chafing dishes (Figure 1), containers for hot charcoal used to keep food warm at table, which were the subject of a paper by Lewis[1]. He has drawn up a classification and has made some tentative deductions as to provenance of the various types discussed. The present authors are fortunate to have been allowed to sample several of the objects referred to in the classification and thus have an opportunity to compare conclusions derived from analytical data with those from stylistic considerations. The second group is of hanging lavers (Figure 2), being another kind of domestic article likely to have been made by the same type of craftsman. Lavers were vessels suspended by a handle or chain which could be tilted to obtain water for washing of the hands from one of the spouts, usually two in number but occasionally one or four.

Fig 2 Hanging laver E16 (Victoria and Albert Museum)

The third group is of candlesticks, included as reference objects since there appears to be general agreement in ascribing provenance to the objects considered. They are of types believed to be Flemish and English respectively.

That the three types of object were manufactured in the 15th century both in England and on the continent may be inferred from their inclusion amongst objects listed in a protectionist Act of 1483/4 'against Straungers Artificers' in respect of 'bokels, Cheynes, latten nayles wt Iron Shankes, Turrets, stondynge Candlestykes, hangying Candlestiks, halywater stoppes, Chafynge disshes, hangynge lavers, Curteyn Rynges'.

Previous analytical work

There have been isolated publications which have included compositional data on copper alloys of the mediaeval and post-mediaeval periods. The number of objects analysed has in most cases been small and some were examined many years ago. Recent publications have provided information on the alloys used in the making of cannons[2], mortars, weights and measures[3] and memorial brasses[4], the last including a discussion of the nature of 'latten'. Berntsen[5] has included data in summary form on a wide range of candlesticks from the 9th to the 19th century and these have been quoted in Michaelis' book on candlesticks[6]. It is interesting to note that none of the candlesticks analysed appear to contain more than 2% lead.

Fig 3 Flemish candlesticks of the socket type C66 (left) and pricket type C55 (right) (Victoria and Albert Museum)

Fig 4 English socket candlestick C161 (British Museum)

The only major programme of analysis of brass and bronze objects of the mediaeval period which has been published is that of Werner[7], who has given data on over 300 objects, mostly from this period. They were mainly objects of a religious character such as crucifixes, reliquaries, holy-water buckets, fonts and censers; even the candlesticks were mainly those for ceremonial use. Thus the data are valuable as an indication of the type of alloy used by the craftsmen of the period for work of the highest quality made in the principal European areas of non-ferrous metallurgical expertise, Flanders and Germany, where most of the objects were considered to have been made. Few of them were ascribed to England, Scandinavia, Italy or France, areas of lesser metallurgical activity.

Practical Details

Samples for analysis were removed from the objects by careful filing, usually from the base or similarly acceptable site, after prior removal of any surface layers at the sampling position. The filings were collected on shiny paper and transferred to glass sample tubes on which full sample identification had been recorded. To avoid cross-contamination of samples, file and paper were carefully cleaned after each use. Sample masses of about 10 mg were typical but these ranged up to 20 mg from large objects. This has proved to be sufficient material for analysis by X-ray fluorescence spectrometry when appropriately mounted.

In the laboratory a sample was carefully spread, as thinly and evenly as possible, on a piece of $6\mu m$ thick Mylar film so as to cover a central circular area approximately 15 mm in diameter. The filings were trapped in position by a short length of Magic adhesive tape, which has been shown to have a very low metal content. This in turn was mounted between two thin cardboard annuli and the whole stapled together. Sample information and reference number were written on the cardboard immediately after mounting. The mounted sample was placed in a 50 mm diameter sample cup and presented to the X-ray source such that the central area alone with the sample filings was irradiated and only the Mylar film interposed between sample and source. The sample chamber was evacuated during the analysis.

The X-ray fluorescence spectrometry equipment was operated using a chromium target X-ray tube operating at

85 KV and 30 mA; further experimental details are contained in an Appendix.

Samples were first subjected to qualitative analysis, for elements of $Z > 25$, by recording the fluorescence spectra over an angular scan of 10-60° 2θ using a LiF200 analysing crystal. The elements present were identified from the characteristic angular position of their principal 'peaks'.

For the quantitative determination of the amounts of elements present, the positions of the 'peaks' were determined to the nearest 0.01° 2θ by step scanning through the 'peak' positions. Appropriate 'background' count angles were determined from the 'peak' profile. Where the 'background' varied only slightly over a limited angular range around the 'peak' position, only one 'background' angle was used. However where there was a sloping 'background', two angles were chosen at approximately equal angular distances on either side of the 'peak'. In the former case the 'peak' and 'background' count rates were measured for equal times; in the latter case the counting time at the 'peak' angle was twice that at the 'background' angles. The full counting sequence is detailed in the Appendix. Adjustment to the counting data was made for the trace quantities of metallic elements in the Mylar/Magic tape using count rates from blanks.

Leaded bronze standards of known compositions were sampled in a similar manner to that used for the objects and the counting sequence outlined in the Appendix was applied to each standard. One of the standards was used as a reference which was assumed to have the composition reported in its specification. The compositions of the other standards were determined using the ratios of their recorded counts against those of the reference standard. The effects of difference in the quantity of sample used was taken into account using a normalisation calculation. The resulting composition values for the other standards were shown to agree with their specified values.

When a batch of samples was being analysed two different standards were included. One was used as the reference material, the counts from this standard being used in a computer programme to calculate the compositions of the samples in that particular batch. This procedure minimised effects caused by any day-to-day variations in experimental conditions. The second standard was treated as if it were a sample and the analysis obtained for this standard was compared with its stated composition; by this means a second check was obtained on the reliability of the experimental method. The values obtained for this second standard were consistently within ±10% of the specified alloy composition for all elements and within ±5% for some of the elements. These errors were thought to be smaller than those likely to have arisen in sampling. There is usually little freedom of choice of the position from which a sample is taken and it cannot be known whether a sample is typical of the whole object; this is a recurrent problem for analysts. However samples were taken from consistent positions over the series of objects by the same technique in order to minimise differences from this cause.

Results and Discussion

The term 'latten' has been used in the title since there is written evidence from the mediaeval period for the use of the word 'latten' to describe copper alloys of 'brassy' colour. However analyses of memorial copper alloys[4] have shown that 'latten' was not a simple copper–zinc binary brass but contained tin and lead additionally; the exact compositional bounds covered by the term are not explored here.

The compositions determined in the present work given in Table 1 are basically from the copper-zinc-tin-lead quaternary, implying deliberate additions of zinc (via calamine), tin and lead to copper under a degree of control by the craftsmen. The additions may in some cases have been of the 'pure' metals themselves but in others have been of pre-alloyed melting stock or scrap articles of less well known composition. Part of the discussion is conducted in relation to these four main elements whose relative proportions are likely to give information on craft practice and material availability. These factors are likely to have differed in different parts of Europe and at different times in the overall period.

The other elements covered in Table 1 are present in the 'latten' at lower levels (although in some cases at high levels by modern standards), and they are regarded as impurities not deliberately added but introduced with the other main metals of the quaternary system or perhaps during processing. The amounts of nickel, iron, antimony, arsenic and silver present were not under the control of the craftsmen except through a choice of the source of his raw materials. A part of the discussion is devoted to a consideration of the value of impurity elements data in indicating the possible sources of the raw materials used in making the 'latten'.

Main alloying elements:

Candlesticks

The results of the analyses for the candlesticks are shown in Table 1. They indicate a well-defined alloy group of leaded brasses with low levels of tin. The candlesticks believed to be of Flemish origin form this group which contains both socket and pricket types illustrated in Figure 3.

A further group is indicated with the three alloying elements present in very roughly equal amounts. This group is less compact but clearly separated from the above group. The socket candlesticks believed to be of English origin form this second group, an illustration of which is given in Figure 4.

It is not surprising that articles believed to have been made in England in the 15th and early 16th centuries have compositions richer in tin and less rich in zinc since tin would have been much more readily available for alloying than zinc (via calamine). Before the mid-16th century most, if not all, of the zinc-containing metal would have had to be imported from the continent since no 'brass' industry existed on any scale until that time. Tin was however available from the West country.

The reverse argument is however true for the continental metalworking industry and it is to be expected that objects believed to have been made in Flanders in the 15th and 16th centuries should have compositions richer in zinc and less rich in tin. Calamine for the production of zinc-rich alloys was readily available in the Meuse region whereas tin had to be imported from England or Bohemia.

It appears to be possible therefore to identify features associated with Flemish alloy composition and so practice, and with English alloy composition and practice. This is of benefit in considering the alloy compositions of the other articles.

Chafing dishes

The alloy compositions of chafing dishes CV43, 44 and 45 are zinc-and lead-rich and would in modern terminology be called leaded brasses. CV44, 45 and, to a lesser extent CV43, are similar in composition to the Flemish candlesticks. The alloy compositions of CV77 and 81 contrast with the above, having a lower total alloy content more evenly shared between zinc, tin and lead in common with the English candlesticks . The composition of CV72 may also belong to this group.

CV35 has an alloy composition somewhat different from the other chafing dishes, having zinc and tin levels intermediate between those of the above groups and a fairly high lead content. Reference to this object is made later in the discussion.

Lavers

Most of the lavers (E13, 16, 17, 18, 23 and 24) were made from leaded brasses having >16% zinc, variable lead, but little tin in common with the Flemish candlesticks.

Lavers E19 and 43 were made from leaded bronzes differing markedly from the above group in having low zinc, high lead and significant tin contents, separating them from the alloys used for both the Flemish and English candlesticks.

Impurity elements

Of the remaining five elements determined, silver is seen to be present in consistently small amounts; of the 31 objects only three had silver contents >0.10%. It is perhaps worth noting that of these three 'silver-rich' objects, two are believed to have been made in England. Iron was present in most alloys at a level 0.35 - 0.7%, with extreme values of 0.20 and 1.03%. The level of this element was likely to be subject to significant chance variation due to pick-up from stirring rods and other equipment coming into contact with the molten metal. Thus it is in terms of the impurities nickel, antimony and arsenic that the discussion is mainly conducted since these are likely to have been derived directly from the raw materials used.

The nickel histogram shows a near-normal distribution about a mean value of 0.30%. This appears to be a feature of the period (15th-16th centuries) as there is evidence from other work by the authors and from Werner[8] that earlier alloys had low levels of nickel (<0.10%) while later alloys had relatively high levels of nickel (>0.50%). Thus the 15th-16th century is seen as a transitional period characterised by varying nickel levels with an intermediate mean.

The antimony and arsenic histograms are further from a normal distribution, the antimony particularly so. Certain points emerge from an examination of the antimony and arsenic levels of the object groups proposed based on major element contents.

The Flemish socket candlesticks, the chafing dishes CV43, 44 and 49 and the lavers except for E19 and 43 have fairly low antimony contents (all but one < 0.35%) and generally low arsenic contents. The Flemish pricket candlesticks however have higher levels of antimony and arsenic than the socket candlesticks, suggestive of a different source of copper and so time and/or place of production.

The English socket candlesticks, the chafing dishes CV35, 72, 77 and 81 and the lavers E19 and 43 have varied levels of both elements, in excess of 1.0% in some cases.

Comparison with stylistic grouping

Antiquarians and archaeologists customarily ascribe dates and provenances to objects largely on the basis of style if other more objective evidence is lacking. An object is compared with similar objects described in the literature or available for examination in museum collections. The extent to which the present analytical data add weight to accepted views or throw light on unusual items is now considered.

In the case of the candlesticks, the dates and origins were assumed for reference purposes since there appeared to be general agreement (eg [6,9,10]) on their being produced in the 15th-16th century period respectively in Flanders and England. It is satisfying to find that groups of candlesticks of closely similar appearance are also of similar composition within their groups but that group compositions differ.

The classification of chafing dishes by Lewis[1] has been referred to earlier. Broadly the objects which he has grouped on stylistic grounds are found together in the present compositional groups. Thus CV43 (C1) and CV44 (C2) are similar in composition to the Flemish candlesticks and may also have a Flemish origin; Lewis suggests 'a continental origin'. Similarly CV77 (D2) and CV81 (D1) are similar to the English candlesticks; they were both excavated in England and of them Lewis writes '. . . it is therefore tempting to consider them of English manufacture'. The present work has increased the temptation. CV72 (B1) and the virtually identical CV35, have intermediate compositions in respect of zinc and tin contents and, while it was earlier suggested that CV72 might belong compositionally with the English candlesticks, it is possible that these two chafing dishes represent a group separate from the supposed English and Flemish groups. Further analyses of similar objects may make the date and origin of this type of chafing dish clearer. CV45 (B2) appears to belong with CV43 (C1) and CV44 (C2) particularly in respect of zinc and antimony contents and may therefore be a modified C-type rather than a B-type chafing dish[1].

The compositions for the hanging lavers are mostly low in tin perhaps suggesting that none is of English manufacture. The majority of compositions, E13, 18, 16, 23 and 24, relate to lavers of similar appearance; these have two spouts (E18 only one) with zoomorphic ends, crude human heads on the rim in which the latten handle is located for suspension (Figure 2). These are similar in composition to the Flemish candlesticks indicating an origin already assumed for this type of laver from stylistic considerations. E17, the finest and perhaps earliest of the lavers, has a high zinc but low lead content and would, from the finely detailed human heads, crenallated rim and the hole-decoration of the neck, be considered an example of 'dinanderie'. At the other extreme of zinc/lead ratio are found the least sophisticated lavers E43 and 19. E43, illustrated by Seymour-Lindsey[11] (Plate 116), has spouts and human heads like the majority but has an octagonal body-form; E19 has poorly formed ends on inelegant spouts and lugs formed in the rim in place of the human heads. Each has an iron handle. This relative crudity and the alloy compositions suggest an origin outside the principal latten-working areas. E19 is very similar to a laver illustrated by Dexel[9] (Plate 272) which is said to be North German c1400.

Conclusions

From this exploratory work on the analysis of copper-alloy objects of the 15th-16th centuries, it is suggested that a contribution can be made to the debate on the origins of such objects based on their alloy compositions. Groups of compositions are found which correspond to objects of similar appearance and corresponding geographical areas are proposed, with a greater or lesser degree of confidence, for some of these as places of manufacture. The definition of these and other areas is likely to improve as the programme of work advances and more objects are sampledfor analysis.

Any contribution made on the basis of analysis should be taken only as reinforcement (or the reverse) of the view formed from stylistic considerations since conclusions formed from analysis are based on probabilities rather than certainties. However the information so derived is additional to that available without analysis and may be particularly valuable in the case of fragments too small for stylistic judgement to be applied.

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TABLE 1

	Laboratory Reference	Cu	Zn	Sn	Pb	Ni	Fe	Sb	As	Ag	Museum	Museum Reference
CANDLESTICKS												
Flemish (socket)	C64	70.7	21.5	0.23	6.45	0.40	0.64	0.10	0.01	0.01	Victoria and Albert	M651-1926
	C65	70.0	19.2	1.43	8.35	0.26	0.52	0.16	0.16	0.04	Victoria and Albert	M435-1926
	C66	69.5	20.3	0.67	8.27	0.45	0.40	0.12	0.22	0.05	Victoria and Albert	M436-1926
	C110	68.4	16.7	1.50	12.4	0.21	0.41	0.13	0.16	0.04	Bonn	69.0173
Flemish (pricket)	C55	70.6	15.9	1.90	9.89	0.30	0.35	0.70	0.24	0.04	Victoria and Albert	M110-1933
	C56	69.3	18.6	1.13	8.63	0.27	0.28	1.39	0.27	0.05	Victoria and Albert	476A-1907
	C57	71.6	16.2	1.14	9.31	0.27	0.38	0.66	0.31	0.05	Victoria and Albert	M19-1919
	C58	72.5	16.2	1.16	8.42	0.26	0.41	0.64	0.32	0.04	Victoria and Albert	M19A-1919
	C59	69.1	17.4	1.59	10.1	0.28	0.42	0.77	0.29	0.05	Victoria and Albert	476-1907
English (socket)	C4	82.8	6.06	4.45	4.68	0.15	0.69	0.56	0.58	0.04	Coventry	49/80
	C6	83.6	7.44	3.42	4.01	0.05	0.67	0.37	0.40	0.06	Coventry	49/81
	C35	81.5	6.34	4.24	6.08	0.31	0.54	0.51	0.40	0.05	Victoria and Albert	M571-1911
	C49	84.8	3.85	4.95	4.26	0.42	0.64	0.31	0.65	0.11	Leicester	112.27
	C103	77.6	9.71	4.82	5.11	0.07	1.07	1.32	0.20	0.08	Robin Bellamy Antiques	-
	C153	83.3	4.59	3.89	6.30	0.12	0.23	1.02	0.49	0.07	Wales-Cardiff	19.151
	C161	82.8	8.17	3.39	3.87	0.25	0.60	0.51	0.37	0.07	British	1915(12-8)181
CHAFING DISHES/ HANGING LAVERS												
Chafing dishes	CV43(C1)*	80.7	14.0	0.81	3.50	0.32	0.47	nd	0.20	0.03	British	60(9-28)2
	CV44(C2)	72.9	15.2	1.04	9.72	0.29	0.56	0.18	0.09	0.03	British	60(9-28)1
	CV45(B2)	75.4	14.6	2.04	6.83	0.35	0.42	0.22	0.18	0.03	British	
	CV35	75.2	8.32	2.70	10.6	0.56	0.41	1.65	0.55	0.05	Robin Bellamy Antiques	-
	CV72(B1)	79.6	8.11	3.28	6.34	0.54	0.50	1.07	0.50	0.06	Wales - Cardiff	67.511
	CV77(D2)	82.9	2.97	5.62	5.71	0.31	0.21	1.37	0.73	0.13	British	1900(10-1)3
	CV81(D1)	85.4	3.67	3.77	4.98	0.31	0.39	0.62	0.76	0.08	Ludlow	
Hanging lavers	E17	74.6	19.4	2.00	2.03	0.56	0.45	0.27	0.52	0.15	Victoria and Albert	M2-1937
	E13	70.5	21.6	0.69	5.83	0.18	0.51	0.40	0.30	0.01	Robin Bellamy Antiques	-
	E16	73.4	15.8	1.71	7.19	0.31	0.64	0.68	0.28	0.03	Victoria and Albert	M2669-1931
	E18	69.5	20.7	0.94	8.05	0.07	0.65	0.03	0.01	0.03	Victoria and Albert	411M-1880
	E23	73.6	14.2	1.91	9.34	0.08	0.49	0.34	0.05	0.06	British	1958(10-2)1
	E24	68.2	15.5	3.32	10.4	0.44	1.06	0.11	0.95	0.08	British	OA291
	E19	74.6	0.61	7.38	14.2	0.15	0.22	2.20	0.61	0.05	Victoria and Albert	M2676-1931
	E43	66.1	4.67	6.15	20.4	nd	0.45	1.62	0.56	0.06	British	1908(7-31)1

* object reference in paper by Lewis(1)

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Biographical notes

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Appendix

Apparatus

Philips X ray spectrometry system comprising:-

PW 1140/90	Generator	PW1410	Spectrometer
PW 1390	Channel control	PW 8203	Single-pen recorder
PW 1394	Motor control	Model 43	Westrex Teleprinter

Experimental Conditions

Tube data : Cr anode 85kV 30mA
Counters : Flow (1816V), Scintillation (1070V)
P.H.S. : Lower level 300. Window 400

Angle (°2θ)	Counter	Counting time(sec)	Usage	Crystal
18.00	↑	40	Background for Sb & Sn	LiF
19.08		40	Sb K_α	220
19.91		40	Sn K_α	2d=2.848Å
15.30		10	Background for Ag	
15.99		20	Ag Kα	
16.70	Scint	10	Background for Ag	
26.50	only	10	Background for Pb	
28.23		20	Pb L_β	
29.90		10	Background for Pb	LiF
30.00		100	Background for As	200
30.46	↓	100	As K_β	
41.81	↑	10	Zn K_α	2d=4.028Å
43.00		10	Background for Zn & Cu	
45.01	Flow	10	Cu K_α	
48.00	+	10	Background for Ni	
48.70	Scint	20	Ni K_α	
49.50		10	Background for Ni	
56.40		20	Background for Fe	
57.55	↓	20	Fe K_α	

Iron Blooms in the North-West Passage

Between the years 1576 and 1578 Martin Frobisher, the Elizabethan explorer, made three voyages 'in search of a passage to Cathay and India by the North-West'. Much of the story of these voyages is recorded by V Stefansson in his 'The Three Voyages of Martin Frobisher' published in 1938 in London in two volumes[1]. One of the things the expedition either made or found were some iron blooms, which were later found with Frobisher's other effects in East Baffin by a later expedition in 1861-2 under the American C F Hall. One of these blooms was deposited in England and one in the USA. For a long time both were considered lost but in 1958 the American one was found in the Arts and Industries Building of the Smithsonian Institution, Washington DC.

This bloom has recently been examined by the Conservation-Analytical Laboratory of the Smithsonian. It weighed 20 lb (9.09 kg) and is roughly hemispherical with a diam of 18 cm. Both the metal and the slag inclusions have been analysed and the results are as follows:-

Metal - % (2)		**Slag - % (3)**	
C	0.051	$Si0_2$	15.6
	0.062	Fe0	54.34
	0.127	Al_20_3	3.20
	0.049	Mg0	0.71
	0.061	Ca0	0.16
	0.048	Mn0	9.49
P	0.6	$Ti0_2$	0.21
	0.84	P_20_5	5.65
		K_20	0.24

The bloom consists mainly of ferrite with a high phosphorus content but in some areas there was some coarse laminated pearlite and some rust. The slag consisted of fayalite crystals, in a glass matrix with some very fine wüstite or magnetite dendrites. The carbon contents given above show the usual heterogeneity of the typical blooms made by the bloomery process, with a low average carbon content. Only metal with this order of carbon content can be in equilibrium with the associated slag. This slag is also typical of the bloomery process and indicates that no secondary operations have been carried out.

In order to throw light on the question of its origin, it was decided to use more recently developed C-14 dating techniques. Previously, the amount of carbon in bloomery iron has been insufficient to obtain C-14 dates without using enormous samples. Even in this case it was necessary to use 2 lbs to obtain 10 mg of carbon sample. Two slightly different dates were obtained and they were 1271 ± 133 and 1158 ± 107 AD. The agreement is good and providing the smelting operation did not involve either fossil fuel or limestone the dates must be valid. The small amount of lime in the slag almost certainly comes from the wood ash, as does the alkali. If these were made on the spot, the wood would certainly be drift-wood of which there is a plentiful supply. Of course this might be several centuries old.

Even so it is concluded that it is unlikely that it was made or brought over by Frobisher in 1578. The alternative and preferred explanation is that it was made or introduced during the Norse occupation of Greenland in the 12th-13th centuries AD.

The composition is very typical of bloomery iron made in Northern Europe during this period with its high phosphorus content and associated high manganese slag. Given the right ores it would be possible to make such iron with drift-wood in East Baffin but if so it is unlikely that it was left around unused. It is more likely to have been left by some earlier migration that either moved on or failed before they could use the metal that they so carefully brought.

During August 1981 an expedition from the Smithsonian Institution visited Kodlunarn Island in Frobisher Bay where Frobisher had landed on the sixteenth century. Three more iron blooms were discovered by the Smithsonian expedition. A charcoal inclusion from a cavity on the side of one of these blooms is being carbon dated.

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Book reviews

Beno Rothenberg and Antonio Blanco-Freijeiro: Ancient Mining and Metallurgy in South-West Spain. *Institute for Archaeo-Metallurgical Studies, Institute of Archaeology, University of London. 1981, 320 pp; 298 figs. ISBN 0-906183-01-4. Price £18.*

A large archaeological survey is one of the hardest jobs that the prehistorian can undertake, and all too often the teams run out of money, enthusiasm, or their results are not as they had hoped they would be. But in the ambitious project to study the pre- and protohistoric metallurgy of SW Spain, Professors Beno Rothenberg and Antonio Blanco-Freijeiro have shown how to design, manage and complete a large-scale project under difficult conditions. In short, the results are a vindication of a well-considered and intelligently designed research programme, and they will be warmly welcomed. The first volume of the fruits of nearly 10 years labour, handsomely supported by Rio Tinto Zinc S.A. among others, is now available, and it is jammed full of invaluable first-hand observations on mines, analyses of ores and slags, surveys of the palaeoenvironment of SW Spain, and short excavation reports on megalithic tombs and proto-historic settlements.

The goals of the Huelva Archaeo-Metallurgical Project were to look into the technological, social, economic and ecological developments and implications of metal production. The Iberian Pyrite Belt, centred in Huelva, was chosen because it was one of the largest and richest mining areas in Europe. This volume records the survey work and clearly could only manage to cover part of the wide range of targets set out as its prime goals. The survey began by 'endeavouring to form a representative profile of the ancient extractive metallurgy of Huelva from its earliest primitive beginnings to the full development of industrial metal production in the Roman era. We started not with a search for ancient remains, but with the study of the mining geology of the province . . .' (p 34). Despite the immense damage done to much of the area by modern reforestation, this was a successful research strategy and proved itself well. The book is in six sections, the chief ones being a long and detailed description of the sites discovered and sampled, followed by a section of the palaeoenvironment based on pollen sampling and palaeosols. The last parts cover the excavation at the ancient city of Tucci, now Tejada la Vieja, and technical descriptions of the analytical procedures used for studying the slags.

The early prehistoric metallurgy was concentrated upon the small ore outcrops that were visible as green or red stains in the quartz dykes that run over the rugged countryside. Stone hammers and mauls were used to work shallow mines and small pits in these dykes; the ores were smelted close by and the slags were pulverised to release prills of copper within them. This phase is hard to date, and the plain pottery is scarce and undiagnostic. There are no C-14 dates – they are promised in future volumes – although the excavators believe a Chalcolithic date is probable for mines such as Chinflon or Masegoso which typify this early form of 'Malachite Metallurgy'.

The later mining works and technologies date from 1000 BC onwards, covering the Later Bronze Age to Roman periods, and move into a different gear altogether. Both silver and copper were produced from the LBA onwards at Rio Tinto, and the LBA mines show a technical improvement over the earlier ones. Prospecting shafts with rock-cut footholds (Chinflon 22) were probably hewn out with metal tools. Bun-shaped copper ingots of 3-4 kg were produced from furnaces which used iron oxide fluxing to make a proper fayalite slag (p 170). The extensive silver smelting of this period was represented at Rio Tinto by slag at the base of the immense section built up at Corta Lago; silver ores (argento-jarosites) were mined from shafts which delved below the thick mantel of hard gossan above it. The ore was smelted with a silica flux, lead was added as a silver collector, and the silver was then cupelled. All this was achieved in the LBA, in pre-Phoenician times. Both copper and silver production was sophisticated and efficient. This technology continued unaltered all through the Phoenician and Carthaginian periods, and silver was extracted in prodigious amounts as the slag heaps show. Under Roman administration in the first century AD, mining was transformed. The shaft-and-gallery system became ubiquitous in the exploitation of the rich silver and copper ores in the secondary enrichment zone of the pyrite bodies. The enormous scale of these imperial workings dealt with millions of tons or ore, fluxes, slag, not to mention huge volumes of charcoal and the supplies of food, water and clothing for the workforce. The authors suggest (p 174) that 'a great part of the energy used (in smelting) derived from the pyrites themselves by some kind of 'pyritic smelting' process' This would certainly reduce the need for unimaginably large quantities of charcoal for the industry!

Horowitz's fine contribution on the palaeoecology shows that there was a higher water table in the past than today, and that olive and vine were present in the prehistoric pollen cores from the lagoon site of Laguna de las Madres. Again, no radiocarbon dates were available for any of the interesting cores analysed, though they are promised for the future, and this hindered his interpretations. Selected excavation at the ancient city of Tucci showed it to have been a major site from the 8-4 centuries BC, when it was abandoned, and metalworking took place within it.

These comments can only reveal a small part of the valuable and interesting mass of detail in this volume. There are sections which will interest the prehistorian, the geomorphologist, geologist and classical scholar, and this book will richly repay those who take the trouble to work their way through it. It is not always easy reading, but that is because there are so many fascinating problems which are only at a provisional stage of investigation. The quantification of the production of silver and copper at Rio Tinto is one such example, and whatever the figures eventually calculated, they will be breathtakingly large, and run into many thousands of tons.

Two final comments are in order. Firstly, the vague dating of many of the older or more primitive sites relies on scraps of plain pottery. As any Spanish prehistorian knows, these are to all intents and purposes undateable, and are one of the reasons why surface survey work is so unrewarding in much of the Peninsula. They may equally well date to 3200 BC as to 1000 BC. Radiocarbon dates are vital, and to have them published later, in another place, makes an unecessary handicap for those of us who are interested in this work. The other matter concerns the future publication of companion volumes. Unless very great care is taken, vital information for many sites will be dotted through two or three separate books and there will be vast confusion over what is actually known about key sites. In an ambitious and important project of this scale, it is not unreasonable to insist that the publication be organised so that all the data for each site or mine be gathered together and published together too. Even Estacio da Veiga did this in his **Antiguidades Monumentaes do Algarve I-IV** (Lisbon

1886-1891). This latter is an important volume, like the works of Professor Martin Almagro Gorbea and Dr Hermanfrid Schubart, which needs to be carefully digested and incorporated into future work at Rio Tinto.

But these points must not detract too much from a most impressive and exciting project, imaginatively executed and brought to prompt preliminary publication. Every archaeologist interested in Europe's later prehistory needs to read this book, and every librarian must buy a copy to see that they can. At £18 it is good value, and we all look forward eagerly to the companion volumes that will amplify it.

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Swedish and Foreign Iron on the 17th Century European Market. (Svenskt Och Utlandskt Jarn Pa 1600-Talets Europamarknad). *A transcription of a 17th century manuscript: Martin Fritz, Nils Bjorkenstam, Karin Calissendorff, Sam Owen Jansson, editors, 1981, published in: 'Med Hammare och Fackla' XXVIII (ISSN 0543-2162) available as a reprint in bookform from Tekniska Museet, Museivagen 7, Stockholm, Sweden. 172 pp, An English translation is available at £7.00*

In 1974 a MS was (re?)discovered in the Norwegian Public Record Office (Oslo) that proves to be of great importance to the study of 17th century iron production and trade in Europe. The MS, written in High German (with strong Swedish influences) is dated 1670. Its title: 'Teutsche und frandsosische Eysenwerk concernirend'. A working party of Jernkontoret (the Swedish Ironmasters' Association) prepared a transcription of the MS. This transcription, together with several related studies and notes constitutes the present book. For the average student of the history of technology the early texts usually are not accessible: they are rare, and usually almost undecipherable, too. Precisely by transcription, texts become more widely accessible. The transcriber of the present MS gives an account of the procedures she followed in a short note (in Swedish). She tried to preserve the character of the text; the changes were mostly confined to spelling, notation, abbreviations and punctuation. When studying the MS it became clear that the preserved version is not the original, but a contemporary (hand-written) copy. It was prepared by a scribe without (full) comprehension of the text and terms used. A number of typical errors resulted. These were corrected in the transcription.

The working party of the Jernkontoret could trace the putative author. He, a Swede by the name of Abraham Cronstrom, was much-travelled and familiar with most of the European iron production centres and markets. His attitude was commercial, but he had a good knowledge of technology then in use. This combination is one of the reasons for the MS's importance. Its date is a second reason. Texts concerning pre-1700 iron production are extremely rare. This MS is dated to c.1650 – the earliest known Scandinavian text at present. A third reason is the contents of the text. Combined with Otto Dress's 'Jarn- och Staltillverkning' (1687, also republished) the MS gives a full description of iron production, both from a technical and economical aspect. A fourth reason is the international scope of the text. The book offers two related studies (in Swedish). The first shows the economic-historical background, essential to full understanding of the MS's detailed information. The second, rather longer study comments on the technical information contained in the MS – in a Swedish context. This section is for the technically inclined an important part of the book. Topics covered are: ore, pig iron production (blast furnaces), wrought iron production (fining, the direct process), steel production (directly from ore, fining of pig iron, cementation of wrought iron), manufacturing (plate, nails, wire, chain, horseshoe bar).

Also added are an extensive Glossary [14 (!) pages, (Old) German to Swedish], and a Register of sites mentioned, with maps.

The main part of the book of course, is the transcription itself, 84 pages in all. The transcription can be read by anybody with a working knowledge of modern German. Abraham Cronstrom's observations are mostly of an economical or technological nature. Purely metallurgical deliberations are not included – perhaps reflecting this period's strictly pragmatical approach to metals production? Many price- and cost-calculations and comparisons are given; alternating with technical descriptions of ore-mining, charcoal-burning, – partly illustrated with sketches – blast furnaces and hammer forges, steel production. Running right through these is an extended report on sites visited during a study tour of the main production centres of the Continent:

Belgium (Liege), Germany (Harz, Westfalen, etc), Northern Spain, Lorraine and Northern France, Austria (Styria), Poland (Danzig).

For the serious student of iron and steel production's history: a must. Strongly recommended!

Alex den Ouden

Medieval Industry, CBA Research Report No. 40. *Edited by D W Crossley. Published, 1981, by the Council for British Archaeology, 112 Kennington Road, London SE11 6RE. £16.*

A review of archaeological evidence for medieval industry. This publication was inspired by the work of the late Professor Eleanora Carus-Wilson in seeking to set alongside each other the documentary and archaeological evidence of the subject.

There is a certain lack of cohesion in the inclusion of a paper on medieval sheep and wool types, rather than on the archaeological evidence for spinning and weaving, which would seem to have been more in keeping with the rest of the material. Neither must one look for a completely comprehensive survey; for instance lead is covered over the whole country, whereas tin is confined to Devon, and makes no mention of the Cornish industry. Doubtless these anomalies arise from the fact that the papers were originally delivered at a meeting, rather than designed as a printed whole.

There are comprehensive sections on medieval milling, the pottery industry, and brick, tile, and glass making. Six out of twelve sections are devoted to metals and these are the ones most likely to interest HMS members.

D W Crossley in 'Medieval iron smelting' has gathered together the present scant evidence on the subject in England from Saxon times, and set it against the rather better documented and prolific evidence available from Europe, up to the introduction of the first blast furnaces.

Professor R F Tylecote, 'The medieval smith and his methods' speaks of the importance of the smith in medieval society; examines hearth types, the simple pit at floor level and the waist high hearth; the steeling of tools and the comparative prices of iron and steel. This leads easily to 'The medieval blacksmith and his products' by Ian H Goodall, who examines the tools made and used by the smith himself, and made by him for many other traces; also for agricultural and domestic use, and for building, as well as personal and horse equipment. Many items are clearly drawn and there is an exhaustive bibliography. Alison R Goodall does the same service for the medieval bronzesmith and his products.

'Lead mining and smelting in medieval England and Wales' by I S W Blanchard traces the development of various smelting methods, and follows the history and topography of all the principal lead fields. T A P Greeves in 'The archaeological potential of the Devon tin industry' gives a comprehensive resume of documentary evidence for working before 1500 AD and of archaeological work already undertaken. He examines the field evidence for working alluvial stream deposits, open cast, and underground mining, with a view to assessing the archaeological potential of the industry in Devon.

Amina Chatwin

Iron making in the Forest of Dean. Rev H G Nicholls, MA. *Originally published in 1866 and reprinted in facsimile, paperback, by Douglas MacLean at The Forest Bookshop, 32 Market Place, Coleford, Glos, 1981, £1.95.*

A welcome reprint of an important and very scarce classic on ironmaking in the Forest of Dean. This unique area with its 'free miners' has a history of ironmaking dating back to Roman times, which Nicholls traces through medieval times, with its 'itinerant forges', right up to the 19th century, with histories and descriptions of many ironworks, long since silent. I J Standing has added a short, but extremely interesting, introduction and select bibliography to update this fascinating little book, written more than a hundred years ago.

Amina Chatwin

Brass, Eric Turner, *HMSO for the Victoria and Albert Museum, 1982, 48 pages. Illustrated. Price £3.50.*

This book is one of a series designed to introduce various aspects of the decorative arts to the general public, to quote from the back of this volume. If the others are as full of mistakes, misquotations, and sheer subject ignorance on the part of the authors then this is a series the public can well do without. Unusually for such a book, the text is devoted almost entirely to the technical and economic aspects of brass production, and the art history is essentially confined to captions which accompany the generally excellent colour photographs. So far so good, however if one is going to highlight the process by which the brass was made, it is surely prerequisite that one actually knows it, if not the result can be disaster. Eric Turner relies heavily on the description given by Theophilus in the ? 12th century, for making brass by the cementation process. One suspects from some of the misquotes and obscure terms that the Dodswell translation was used. This edition although grammatically correct, is a very straight translation with no attempt to explain textual difficulties. It is thus full of snares for the technically unwary. Turner falls unerringly into every one, and even sets a few more for himself that are not in the original text.

Let us have a sample. According to the Turner/Dodswell version of Theophilus the zinc ore was mixed with *coal*, heated until red hot, placed in a crucible with copper *ore* and covered with *coal*. The crucible was designed to *allow air to pass* freely through the mixture. In fact zinc ore, *charcoal* and *metallic* copper were fired in a *sealed* crucible. Dodswell translates *carbonibus* as 'coals' in the medieval sense of the word, ie charcoal. Copper ore is a straight miscopying by Turner, and the reference to the crucible being open to allow the air to pass freely through represents a misunderstanding by Turner. One can see how it came about: Dodswell's version says 'poke the opening with a stick so the ashes are cleared and more air can get in'. If one reads the preceding paragraph it is obvious that the crucibles are already set in position, and it is the furnace which is being poked.

Moving onto the decorative processes we are told that brass was usually silvered by a process which was identical to fire gilding except that powdered silver was amalgamated with mercury and not gold. In fact silver amalgams were very rarely used, the usual process for brass was the so called French method by which thin silver sheets were burnished onto the brass. On copper of course the fusion welding process of 'Sheffield Plating' was employed.

If technology is above, beneath, or at any rate beyond Turner perhaps the more arts orientated etymology and history of the subject might be more in his line. Etymology? Take the derivation of the word bronze. The derivation and early use of this word is one of considerable debate amongst historians of science. It probably derives from *Brindisium* used in the *Mappae Clavicula* to describe the high tin bronze alloy of which the Romans made their mirrors, and the first use of the word bronze is in late Medieval Italian documents. Turner has Theophilus using the term in the ?12th century. In fact, Theophilus uses the term *Aes*, a blanket term denoting either copper or a copper tin alloy and in the particular reference to which Turner alludes, *Aes* clearly means copper. History? Take for example the description of post Medieval brass. Here the manufacture of brass in Britain proceeds without mention of Bristol, apparently it all happened in Birmingham from the late 17th century onwards.

The implications and consequences of these errors are serious and most regrettable. This work is intended as a general guide issued from one of our most prestigious national museums. The interested layman will treat this work as authoritative. Yet the author and his editor clearly have failed to consult with a technical expert or even any of the standard technical histories. The usual attitude of the Art Historian to the realms of science or technology is to ignore them, the attitude displayed here is even more cavalier and damaging. That such work could be published by HMSO from an institution of the Victoria and Albert Museum standing is both sad and disquieting.

Paul Craddock

Abstracts

GENERAL

K Goldmann: Sand casting – the principal early European bronze casting process? *Archaeol Korrespondenzbl, 1981,* **11**, *109-16 (in German).*

Outlines a possible method for casting prehistoric bronzes in fine sand in a 3-part wooden mould which would leave no archaeological trace. BAA

W R Opie, H P Rajcevic, E R Querijero: Dead roasting and blast furnace smelting of chalcopyrite concentrate. *J of Metals, July 1979,* **31**, *(7), 17-22.*

This paper describes a minimum pollution process for smelting dead-roasted chalcopyrite concentrate directly to blister copper in a blast furnace. The process depends on converting the preponderant portion of the iron in the concentrate to its highest valence oxide during dead roasting and on minimizing residence time of the charge in the furnace during smelting by operating a furnace with an unusually low-charge column. Technical and economic advantages of the process include excellent sulphur control, low capital cost, high metal recoveries, energy conservation and flexibility of operation. ECJT

D C W Sanderson and J R Hunter: Composition variability in vegetable ash. *Sci & Archaeol, 1981,* **23**, *27-30.*

In preparation for a programme to characterize fragmentary glass from post-Roman and early medieval periods in Britain, some research into the characteristics of seaweed ash (from N Yorks coast) and wood ash (from the Weald) was conducted using atomic absorption spectrophotometry. The high degree of variability found could have been a source of difficulties for the glassmakers. BAA

W Walchli: Touching precious metals. *Gold Bull, 1981,* **14**, *154-8.*

Brief account of the touchstone test for gold, silver, and platinum as regularly (and historically) used in the jewellery industry. In most cases it is of acceptable accuracy, and is also rapid and requires only a very small amount of test alloy. Gives a table of acid solutions used for different finenesses. BAA/CBA

W S Robinson: Observations on the preservation of archaeological wrecks and metals in marine environments. *Internat Journal of Nautical Archaeology and Underwater Exploration, 1981,* **10**, *(1), 3-14.*

The importance of the environment in the preservation of wrecks is discussed. Physical movements of seawater and marine sediments, and the effects of marine wood-boring organisms can cause destruction of organic materials.
Cast iron transforms to a matrix of porous oxidation products interlaced with graphite flakes (in grey cast iron) or iron carbide structures (white cast iron), which preserves the shape of the artefact, but causes loss of strength. Wrought iron and steel often form 'mould' concretions, in which the original artefact is replaced by a cavity encased within a hard ferrous concretion shell. From these, casts may be taken and a replica made of the original artefact. Copper and copper alloys show varying resistance to environments containing dissolved oxygen, and to sulphide – containing environments, for reasons which are not clear. Similarly the effect of burial environment on pewter is unclear.
Sulphides can cause considerable corrosion to lead. APG

W A Oddy and N D Meeks: Pseudo-Gilding: an Example from the Roman Period. *Masca Journal, 1981,* **1**, *(7), 211-213.*

Analysis of surface deposits on a small leaded brass Roman bust indicate that two separate surface coatings had been applied, the first to imitate silver colour and the second to imitate gold. The first coat was of tin, the second was mixed sulphide of iron and copper, secured by soft tin/lead solder to the tinned surface. This discovery throws some light on early recipes for imitation gilt finishes.
APG

BRITAIN

T Boyns, D Thomas and C Baber: The Iron Steel and Tinplate Industries 1750-1914. *Glamorgan County history, Volume 5, Chapter 3, pp 97-154. Ed Arthur H John and Glanmor Williams, University of Wales Press for County History Company, Cardiff, 1980.*

After very briefly outlining the development of ironmaking processes, the account outlines the early development of the iron industry (1750-1790), the introduction of steam power, and the puddling process, the era of expansion (1835 - 1850) the end of the iron era, steel manufacture in north Glamorgan, the movement to the coast, developments in West Glamorgan (chiefly to supply the tinplate mills) and organisational concentration. Tinplate production is reviewed in a separate section.

J K Almond: The Royal School of Mines and 19th Century Steelmaking. *The Royal School of Mines Journal, 1980 (30) 18-21.*

Briefly traces the work of some of the staff and former students of the school in the steel industry in the latter part of the 19th century. Amongst those mentioned are Edward Riley (works chemist at Dowlais, later consultant in London), Dr John Percy, Walter Child (chemist and manager at Dowlais), George James Snelus (Dowlais and West Cumbria), Arthur Willis (chemist, Landore Siemens Steel), W H Greenwood and William Hackney (Siemens Steel), Henry Louis (eventually professor of mining at Newcastle), J W Westmoreland (Rhymney Iron Co), J P Walton (Wishaw, Frodingham and Consett) and P C Gilchrist and S G Thomas (of basic Bessemer fame). APG

W K V Gale: Development of Founding in the West Midlands. *Foundry Trade Journal, 1982,* **152**, *(3233), 336-342.*

The Birmingham area had no metal ores, very little water-power, and no other natural advantages at all. However, it had a nucleus of craftsmen accustomed to working metal and from the 1660s there was an influx of people, many of whom were either persecuted for their religious beliefs in their home areas, or prevented from exercising their skills by the guilds in larger towns and cities. These circumstances led to the development of the brass industry in the area. The availability of raw materials ensured that the Black Country developed as an iron founding centre, particularly when coke replaced charcoal as a fuel and steam power replaced water power. Under guidance of successful entrepreneurs such as Matthew Boulton, trade prospered, and the area successfully adapted to meet changing circumstances, so that area still has the largest concentrations of foundries in the country. APG

S C Hawkes ,G Speake and P Northover: A 7th century bronze metalworker's die from Rochester, Kent. *Frühmittelalt Stud, 1979,* **13,** *382-92.*

The die, from a disturbed context in the town, is a cast copper alloy strip for the production of repoussé metal foils, probably for drinking cup mounts. The decoration shows a Style II animal, probably mid-7th century. BAA

E H Horton: The History of Redbrook Tinplate.Works from 1930-61. *Gwent Local History, 1982,* **52,** *13-23.*

E Kennerley: Caerleon Mills and Ponthir Tinplate Works. *Gwent Local History, 1980,* **49,** *18-24.*

A scholarly account, with 25 references. Finds no evidence of any copper industry in Ponthir, or of any tinplate industry before 1758, as has been stated by J F Rees. HWP

S M Linsley: Hareshaw & Ridsdale Ironworks. *Industrial Past, 1981,* **8,** *(2), 10-13, 1981,* **8,** *(3), 12 and 13.*

Historical notes and site descriptions of blast furnaces near Bellingham, Northumbria. Sketch drawings and map. (Reproduced from 'Northumbriana' magazine). HWP

C McCombe: The Cartmel Obelisk – a Monument to the Eccentricity of 'Iron-mad Wilkinson'. *Foundry Trade Journal 1981,* **151,** *(3223), 618-620.*

The article relates the saga of John Wilkinson's burial in a cast-iron coffin and describes the 19th century cast iron monument in detail. APG

P D Goriup: Reading's Impossible Cast-iron Lion. *Foundry Trade Journal, 1981,* **151,** *(3225), 739.*

A description of a cast-iron 31 ft long lion in Forbury Gardens, Reading. The 'impossible' refers to the walking posture depicted. APG

H Green: Melin-y-Cwrt Furnace. *Trans Neath Antiquarian Society 1980-81, 43-75.*

A Briton Ferry Estate lease of Melin-y-Cwrt furnace dated 1793 with a surveyor's plan annexed gives new information on the furnace. The system of leats supplying the water wheels is described. The 1793 plan shows kilns for burning the iron ore, a great furnace for melting the ore, a small air furnace, kilns for calcining the ore, a smith shop, and an undershot waterwheel to provide blowing power for the blast furnace. The text of the lease strongly implies that charcoal was the blast furnace fuel.

By 1798, the works is described as having a finery and a foundry in addition to the blast furnace. APG

J Pickin: The Ironworks at Tintern and Sirhowy. *Gwent Local History, 1982,* **52,** *pp 3-9.*

Brief descriptions of recent excavations. HP

P T Craddock: A Medieval Islamic Brass Trapping found at Rochester. *Kent Archaeological Society, 1981,* **97,** *296-298.*

The trapping is of brass with 11% zinc, 2.4% tin etc. It was found in Rochester and is one of only a very small group of artifacts likely to have returned with the crusaders. Author

T E Evans: Furness Iron – Part 2. *In 'Industrial Past' Spring 1981, 8, pp 10-13.*

Historical notes concerning Nibthwaite, Penny Bridge, Newlands and Duddon furnaces, the iron trade and John Wilkinson. HWP

S Needham: The Bulford-Helsbury manufacturing tradition: the production of Stogursey socketed axes during the Later Bronze Age in Southern Britain. *Brit Mus Occas Pap,* **13,** *1981, 72 pp, figs, tables, refs. Price £3.50 (paper ISBN 0 86159 012 0)*

The finding of two moulds for Stogursey-type axes prompts a re-evaluation of a small group of moulds and of its relationship to cast products (catalogued here). They represent a distinctive manufacturing technology with two regional groupings in southern England, and a Welsh group as yet lacking mould finds. Product: matrix recovery rates can be calculated and the equivalent deposition: production ratios assessed. Implications for the socio-economic position of smiths are discussed. BAA

I M Stead, A P Hartwell, J R S Lang and S La Neice: An Iron Age Sword and Scabbard from Isleham. *Proc Cambridge Antiq Soc, 1980,* **70,** *61-74.*

TL 654755. The iron sword and incised and punched bronze scabbard were harrowed up in 1976. The bronze composition was analyzed and SEM examination of the sword revealed a piled structure. The scabbard is a native product comparable with Witham and Battersea examples of 1st century BC. Votive deposit in old river bed? BAA

M G Spratling: Metalworking at the Stanwick oppidum: some new evidence. *Yorkshire Archaeol J, 1981,* **53,** *13-16.*

Two previously unrecognized finds from Wheeler's excavations are a fragment of mould gate and one of ?tuyere. Some details of the Stanwick Hoard are corrected and a rather more complex economy than Wheeler proposed should now be envisaged for mid-1st century AD. BAA

G Webster, J Watson, J Anstee and L Biek: The Swords and Pieces of Equipment from Excavations at Canterbury Castle. *P Bennett, S S Frere and S Stow, 1982, pp 185-190.*

Two 2nd century AD Roman long swords found in a double grave. One sword shows 'proto pattern welding' of single filed bar twisted one turn per 25mm. The other sword is of four filed bars, welded, forged and ground. PTC

R O Roberts: The Smelting of Non-ferrous Metals since 1750. *Glamorgan County history, Volume 5, Chapter 2, pp 47-95. Ed Arthur H John and Glanmor Williams, University of Wales Press for County History Company, Cardiff, 1980.*

This is primarily an account of the smelting of copper, zinc, lead, silver and nickel, chiefly in the Swansea valley, but briefly covering Neath, Penclawdd, Loughor, Maesteg, Cwmafan, Briton Ferry, Cardiff, Port Talbot, Resolven. There are sections on the advantages of the location, changes in output and employment, enterprise and capital, labour, the works and processes of production, commercial aspects, and decline. A useful table gives a chronological account of forty-four works in the country. APG

R O Roberts: The White Rock Copper and Brass Works near Swansea 1736-1806. *Glamorgan Historian, 12, 136-157.*

Using extensive documentary evidence, the author emphasises the inducements offered by a coal owner to secure the establishment and operation of this works. Information on the output is provided and photographs of the ruins taken in 1960 are reproduced. APG

R O Roberts: Enterprise and Capital for Non-ferrous Metal Smelting in Glamorgan 1694 - 1924. *Journal of Glamorgan History. Morgannwg, 1979,* 23, *48-82*

A very useful paper on the origins and the social and financial side. APG

A Rodell: New Rails for Old. *Railway Magazine, March 1981,* 959, *pp 140-142.*

An account of Bessemer's method, and its application to rail manufacture. HWP

C H Morris: Scoria Blocks. *Cleveland Industrial Arch 1981,* 13, *23-32.*

In the years after 1880 much of the slag output of the Cleveland blast furnaces was made into street paving blocks. This paper gives the composition of several slags (all with alumina) the shapes of the blocks and some details of the machines for casting them. They were exported world wide. RFT

EUROPE

G E Afanasyev and A G Nikolayenko: A bloomery furnace of the Saltovo type. *Sov Ark 1982 (2) 168-175. In Russian.*

Belgorod district. 8th - 9th century AD. This furnace closely resembles the Czech, Zelechovic-type shown by Pleiner. It is built into a bank and has two inclined tuyeres. Slag and products were withdrawn through the same inclined opening. RFT

D Bialekova: Early Slav blacksmith's work. *Ars Slovaca Antiqua volume (in Czech).1981, Bratislava. Summary in German.*

An excellent book describing important Slovakian finds relating to the craft of the early medieval blacksmith, using good photographs not only of tools, bars etc. but also of artistic artifacts and of medieval iconography. List of chapters (the titles are in Slovakian): Ore resources, The Black Craft, The Blacksmith's Work in Great Moravia, Art and the craft of the Smith, Epilogue, Explanation of terms, Catalogue, Select Bibliography. CPSA

H Brinck Madsen: Tuyeres. *In: Excavation at Helgo VII. Stockholm 1981, 95-105 .*

A study of various tuyere fragments found in building no. 1 of the Helgo site. The main type was a clay brick-shaped tuyere used in metal workshops. Mapping the distribution areas of the dig. CPSA

D W Buck: On the metallurgy of the tribes of the Billendorf Group. *Ethnographisch-archaologische Zeitschrift, 1981, 22/4, 657-667. (In German).*

During periods HC-HD and La Tène A, iron gradually replaced copper alloys in the Billendorf culture, which followed the Urnfield culture in Central Germany. The change first affected implements. The process of innovation seems to have been more rapid in the eastern regions (Neisse-Bober river basins) where trade routes contributed to the introduction of imported metal, and, later of technological ideas. CPSA

T S Wheeler, J D Muhly & R Maddin. Mediterranean trade in copper and tin in the Late Bronze Age. *Annali Instituto Italiano di Numismatica, 1979, 139-152.*

Suggest the eastern Mediterranean copper trade, and perhaps that in tin as well, were based on Cyprus. Mining and smelting may have been controlled by a central administration. The products were sold at the great ports, in some cases to private entrepreneurs who must have bought, sold and worked metals as they travelled the Mediterranean littoral. When in the later part of the Late Bronze Age, the Sardinian metalworkers introduced their products into the international metals market, they facilitated sales by adopting the typical weight and shape of copper ingot developed in the East. APG

B G Scott: Goldworking terms in early Irish writings. *Zeitschrift fur Celtische Philologie, 1981,* 38 *,242-254 .*

Irish gold is panned from alluvial deposits. All Irish goldworking vocabulary is directed towards the processing of this source material. The wide terminology used to describe aspects of alloying, purification and assaying, and gold 'overlaying' is considered and discussed. APG

N H Gale, W Gentner and G A Wagner. Mineralogical and geographical silver sources of archaeic Greek coinage. *Metallurgy in Numismatics, 1980,* 1, *3-49.*

Silver coins, mainly from the Asyut hoard, were analysed for Bi, Au, Cu, Pb, for traces of Na Mn Co Ni As Sn Sb Ir, and for lead isotope compositions. The characteristics of the ores which might have supplied the silver, or in some cases lead for processing the silver ores, were examined, and the results compared in an attempt to discover the sources of the silver. In view of their early date, it seems likely that the coins consist of unmixed primary silver, the mixing of silver from diverse sources not occurring until later. Coins from the Athens mint are made from silver from Laurion.

Most other archaic Greek coins are made from silver from Laurion, Siphnos or a third unknown source. The mints of Thasos and Acanthus draw on various sources not yet identified. Only 3 coins out of 112 have lead isotopic compositions which make it remotely possible that their silver derived from Los Linares or Rio Tinto. APG

M F Gurin: Metallographic investigations of iron artifacts from Abidnya, Belorussia. *Sovetskaya archeologia, 1980,* 4, *251-259.*

The site of Abidnya in the Mogilev region yielded features of the Zarubincy culture, dating from 2nd-5th centuries AD. 24 iron objects were investigated by metallography. Knives and sickles prevail in the assemblage. Unhomogeneous iron and steel structures characterize the manufacturing technology. Quench hardening was applied in 5 cases (hardness up to 600-700 HV). One knife had a welded-on steel edge. CPSA

F Delamare, G Nicolas and E Mencarelli: Study of the forging of an early iron bar. *Revue de Metallurgie (MES), 1982,* **79**, *(2), 97-104. In French.*

A spitzbarren-type bar, one of three recovered from the Saone during dredging operations, was examined in detail. Its surface was covered with a crust which was mainly Fe_2O_3 and FeOOH, with traces of CaO and MnO. Analysis of the metallic phase in the centre of the bar showed C 0.02%, O 0.110%, S 0.04%, Si 0.01%, Ni 0.02% and less than 0.01% each of Mn, Cr, Cu and Mo. Metallographic examination showed numerous closed pores, slag inclusions, some wood charcoal and very variable content of carbon.

Microprobe analyses of four slag components are given. It is concluded that the thermomechanical history of the bar is as follows:

1) Preparation of the metal in the solid phase, reduction being incomplete.
2) Cooling the bloom.
3) Possible splitting of the bloom.
4) Forging at temperature between 1370 and 1450°C, with decarburisation of zones around slag inclusions.
5) Maintained 45 minutes at temperature in excess of 1300°C with further decarburisation round slag inclusions.
6) Slow cooling.
7) Ageing – 25 ± 3 centuries at ambient temperature, probably at the bottom of the Saone.

The metal showed surprising resistance to atmospheric corrosion. Anodic polarisation curves from a fine-polished specimen from the bar show a greatly extended passivity zone as compared with alloy XC10 in 0.1 m sodium bicarbonate. The reason for this is not known. APG

L Donceva-Petkova: On iron making and working at Pliska, Bulgaria. *Archeologia, 1980,* **4**, *27-36. In Bulgarian.*

Hearths of three destroyed smelting furnaces near the western fortification wall, 2 loaf-shaped iron blooms (ca 2-3, 6 kg), 1 reforged brick-shaped bloom (3,35 kg). Dating: 9th-10th centuries AD. CPSA

P Gherghe: The Geto-Dacian city of Socu-Barbatesti. *Materiale si cercetari archelogice a XIV-A sesiane anuala de rapoarte, Tulcea 1980, 186-190.*

Long tongs with flat jaws, for handling strip iron. 2nd or 1st century BC. CPSA

R J Harrison: A tin-plated dagger of Early Iron Age from Spain. *Madrider Mitteilungen, 1980,* **21**, *140-146.*

A Hallstatt period iron dagger with the hilt covered by a thin layer of pure tin, presumably in imitation of silver. Now in the British Museum. CPSA

A Hyenstrand: Remains of the early iron trade. *In: Excavations at Helgo VI. The Maleren Area. Stockholm 1981, 38-40.*

In Sweden, there are about 5000 sites connected with early iron smelting, which developed in 5 chronological phases from the beginnings in the Early Iron Age until the 19th century. Ecological, demographic and economic aspects of the early industry which turned to intensive activities in the Vendel period in the 6th-7th centuries AD. Models of organization of labor from mining through to the distribution of iron bars. CPSA

V D Gopak and F M Zavernyaev: Iron artifacts from the Pochep site. *Sovetskaya archaeologia, 1981,* **1**, *181-191. (in Russian).*

Metallographic analyses of 16 iron objects were made in course of the investigation of materials from the Zarubincy culture site of Pocep, region of Bryansk. They date from the 1st-3rd centuries AD. They were mainly knives and sickles ,made of wrought iron; in several cases steel was observed. Heat-treatment was used only occasionally. Some of the blades were manufactured by welding iron to steel (maximum hardness 464 HV). The technical standard seems to have been rather low. Local iron smelting is postulated. CPSA

L S Khomutova: The history of the iron working industry at the pre-Slavic settlement of the Volga-Oka doab. *Summary of a dissertation, Institute of Archaeology, Moscow, 1981. In Russian.*

Comparisons between the iron technology of the Djakovo culture and that of the Mordva & Murom, which are of Fino-Ugrian origin. The conclusions are based on metallographic examination of groups of iron artifacts, mainly implements. The level of skill of the Djakovo culture was obviously higher than that of its neighbours. CPSA

A Knape: Survey of the iron from Building Group 3. *In: Excavations at Helgo VII. Stockholm, 1981, 63-94.*

Statistical and topographical surveys of iron finds in excavated areas at Helgo, an Old Scandinavian settlement centre in the Maleran lake system, Sweden. The survey includes scrap iron (1550 pieces of 5.5 kg total weight), rods, rivets, nails, sheet, spikes etc. Distribution maps of the dig. CPSA

H Knoll *et multi alii:* **Pliny the Elder on iron.** *Archiv fur das Eisenhuttenwesen, 1980,* **51**, *487-92.*

Philologists, scientists, and engineers combined to provide new understanding and fuller translation of passages on iron production in the *Naturalis Historia* of 1st century AD, considered the standard scientific reference book until medieval times. BAA

G Grimlund-Manneke: Iron ore on Gotland? *Arkeologi pa Gotland. Gotlandica, 1979,* **14**, *79-180. In Swedish.*

Another discovery of 1st century bloomery furnace raises the question of the local occurrence of iron ore on the Isle of Gotland. CPSA

S J Korenevsky and V G Petrenko: A Maikop culture mound at Inozemstevo. *Sov Ark 1982,* **2**, *96-112. In Russian.*

Stavropol area dated to EBA. Analyses show copper-arsenic and copper-arsenic-nickel alloys. RFT

A Kokowski: Smiths' graves in Europe, 4th century BC to 6th century AD. *Archeol Polski, 1981,* **26**, *191-218. (In Polish).*

Studies 47 graves of Central and Northern Europe which contained blacksmiths' tools, with particular attention to tongs and hammers. Some hypotheses on the social status of smiths, the range of products, and the tools of the workshop itself are set out. An Isle of Man site is included. BAA

J Krokosz: Poland's Mighty Bell. *Foundry Trade Journal, 1982,* **151**, *(3228), 936.*

An English summary of an article 'The Zygmunt Bell and other Wawel Bells', in Przyglad Odlewmicwa, 1981, 7, 234.

Hans Beham from Nurnberg was chosen to supervise the casting of the eight ton bell at an existing Krakow arms foundry which was specially enlarged for the purpose. Cleaning and tuning took a full year, and the bell was struck for the first time on July 12 1521 in the presence of the Royal Court. It is still rung on great church and state holidays.

Bells were first cast in Poland between the end of the 11th and the beginning of the 12th centuries. The oldest surviving bell in Poland is the 'Nowak' in Wasel, cast in the second half of the 13th century. The supporting beam is of grey iron bearing the date 1541, possibly the oldest casting of this metal to be found in Poland. APG

V D Lenkov and S A Shcheka: An attempt at determining the raw material base of the Chzhurchzhenien iron metallurgy using physico-chemical analysis. *Sov Ark, 1982,* **1**, *195-203. (In Russian).*

In the area around Vladivostok. A full analysis including trace elements of ores, slag and artifacts from sites in the area of Primorye territory. Used widely distributed Skarn ores which are of no industrial importance today. Mainly magnetite. Trace elements only given for slags. RFT

M Maggetti and F Gloor: Mineralogical and chemical investigations on copper melting crucibles from Burgaschiee *Bull. Soc. Frib. Sc.Nat. 1978,* **67** *(2), 174-180. (In German).*

The inner surface of the neolithic melting pot from the Burgaschisee contains black (chalcopyrite) and red-brown material (goethite). The use as melting pot or as lamp is discussed. Author

J Kocich, M Leukanicova: The application of the electrolytic pipette Elgyres in the metallographical examination of archaeological finds. *Historica Carpathica, 1980,* **11**, *289-293. In Czech.*

Polishing of minute areas on the surface of artifacts by a device developed at the Skoda Works at Plzen. These areas are suitable for any form of microscope observation in this non-destructive technique; however, it should be added that this procedure cannot replace normal examination of blade sections. However, it offers a more rapid means of preliminary examination if large groups are to be investigated. CPSA

I Martens: Some reflections on the production and distribution of iron in Norway in the Viking Age. *In: Economic Aspects of the Viking Age (D M Wilson, M L Caygill eds). British Museum Occasional Paper No 30, London, 1981, 39-46.*

There are about 200 bloomery sites with two relevant types of houses recorded in the Hardangervidda, Mostrond area, Norway. 19 of these have been excavated. A slag heap of 5200 kg represents the production of about 1820 kg of iron. The output of that region in the 6th-13th centuries AD is estimated as 4 tons of iron per year. Typical export economy by comparison with the fjords of Western or the lower areas of Eastern Norway. The testimony of hoards of iron artifacts for the economy of Norwegian regions. Iron bars. CPSA

M Martin: Bronze founders at Augst. *Archaologie der Schweiz, 1978* **1** *(3), 112-120. In German.*

Heavy tongs for lifting crucibles were found in Roman foundries. CPSA

V K Mikheyev: Pendants with two symmetrical horse heads from Sykhaya Gomolsha burial. *Sov Ark 1982, 2, 156-167. (In Russian)*

Kharkov district: 8th-9th century AD. Nine analyses show low tin bronzes mostly with Zn and lead. RFT

J B Mohen: Iron Age in Aquitaine. *Memoires de la Societé Préhistorique Francaise, 1980,* **14**,

This analysis of the origins of the Early Iron Age in Aquitaine contains a chapter devoted to the metallurgy of iron (pp 35-59). In addition to literary explanations, reference is made to the metallographic examination of a sword from Ossun, Hallstatt period tumulus 17 L (ferrite, tertiary cementite), bi-pyramidal iron bars from Macon (Saone-et-Loire), blacksmiths' tongs from Nages, Entremont, Mailhac, and a bloom from Mun (6.5 kg, Roman). CPSA

S T Olteanu, N Neagu and D Seclamen: The technology of the extraction of iron and the problem of the historical continuity on the territory of Romania during the first millennium AD. *Studii si cercetari de istorie veche si arheologie, 1981,* **32**/*2, 217-232. (In Romanian).*

Main sites with bloomery shaft furnaces finds, dating from the Dacian to the Early Medieval periods: Doboseni, Sercaia, Fizes, Sirna, Ghelari. CPSA

S P Packova, V D Gopak: Ironworking in the Hryncuk hill-fort. *Arheolohyya Kyiv, 1981,* **36**, *54-66. (In Ukrainian).*

A forge from the 12th-13th century AD. Metallographical analyses of 57 iron objects: all-steel artifacts predominate, with sporadic iron-to-steel welding; majority simple objects. CPSA

K Peschel: Iron objects of the Hallstatt period in Central Germany. *In: Beitrage zur Ur – und Frühgeschichte, 1981,* **1**, *(Berlin), 542-582. (In German).*

A list of early iron artifacts, consisting of 383 items dating from the entire Hallstatt period, 6 of them belong to the HB period (beginning of the 1st millennium BC). CPSA

J Piaskowski: Metallographical examinations of early medieval iron objects from the Pomeranian-Prussian border. *Rocznik Elbeski, 1979,* **VIII**, *321-351. In Polish.*

27 iron objects from 5 sites were investigated; they are lodged in the castle museum at Malbork. In the majority the simplest technology for working phosphorus-rich iron was applied. One 'sandwich' construction knife with steel core. Plate captions confused. CPSA

H Pirkl, R Pittioni, M Rupert and G Sperl: Studies in Industrial Archaeology and on Iron Smelting in Winkl by St Johann, Tirol. *Anzeiger der phil-hist-Klasse der osterreichischen Akademie der Wiseenschaften, 1981,* **118**, *222-239. In German.*

Undated slag and tuyeres; mineralogical analyses indicate a typical bloomery slag (wustite/fayalite), presumably smelted from limonites. Historical records of hammer-mills since late 15th century AD CPSA

R Pleiner: The technology of the blacksmith. *An appendix in: M Richter: Monumenta Archaeologica, Praha 1982,* **20**, *298-300, pl 40-64. In Czech.*

The book reports the archaeological excavations carried out at Hradistko, a monastic production site belonging to the Ostrov monastery in the Vltava valley, Central Bohemia, in the 13th century. The appendix deals with smithing technology at the site, in the light of 59 iron objects found in two areas of the town that were metallographically examined. The paper includes comments on methodology, results of examination, construction of blades (mainly knives: usually with welded-on steel edges, 7 pattern-welded blades; then of scissors, chisels, miner's picks, axes, etc), heat treatment (fully mastered), productivity of labor (categories of artifacts),, chemical composition (high phosphorus content). A picture of the level of the handicraft of the urban blacksmith in the high Middle Ages of Central Europe. CPSA

R Pleiner: Investigation of the early bloomery process. *Das altertum, 1982,* **28/1**, *49-57. (In German).*

Recent results and methodology of early iron metallurgy research in Europe. Excavations of furnaces, their typology: principles of the bloomery process, mineralogical and chemical investigation of bloomery slags, smelting experiments, metallographical examination of smelted products, economic aspects of early bloomery centres. CPSA

Z Maric: The hoard found at the Illyrian town of Daors. (2nd century BC). *Glasnik zemaljskog muzeja Bosnei Hercegovine u Sara-jevu. Archaeologija, 1979,* **33**, *23-115. In Serbian*

A huge hoard of 245 items, weighing 34 kg, discovered in 1977 at the site, the incomplete name of which begins 'Daors'. The implements there include blacksmiths' and metal workers' tools as anvils, hammers, a pair of pivoted vices, large tongs, and moulds. The objects were buried in a cauldron. CPSA

I Valter: Arpad period forge at Csatar, *123-131.*

P Kishazi: Results of mineralogical-petrographical and economic geological researches carried out on iron ore and slag samples taken from ancient iron metallurgy finds in Western Hungary, *149-156.*

Roasted sedimentary ores of the Burgenland provenance, fayalite-wustite type bloomery slags.

G Vastagh: Aspects and results of testing ores and slags, *157-164.*

The minimum Fe content of ore for use in the bloomery process should be approximately 40%. CPSA

J R Weinstein: Preliminary Analyses of Copper, Bronze and Silver Artefacts from Lapithos, Cyprus. *Masca Journal, 1980,* **1**, *(4), 106-109.*

Material from the Early Cypriot phase (ECI, about 2,300 BC) to the middle Cypriot phase (MC III, about 1600 BC) was examined. Three EC daggers and one early MC sword were essentially pure copper with a low concentration of iron or iron sulphide particles, the metal having been cast, then alternately annealed and hammered, and left in a lightly cold-worked state. An unusually shaped MC I dagger was left in a heavily cold worked state, though still of unalloyed copper containing copper/iron/arsenic and copper/iron/sulphur particles. An EC III awl was probably cast in a closed mould, then hammered but not annealed. Toggle pin shafts were cast, or hammered from a thick copper wire, then annealed. The more corroded samples misleadingly give an impression of a composite structure due to fabrication from a bundle of wires. A silver ring had traces of iron and chloride, but no lead. APG

E A Slater & J O Tate: Proceedings of the 16th International Symposium on Archaeometry and Archaeological Prospection, Edinburgh, 1976. *Edinburgh Nat Mus Antiquities Scot, 1980, 439 pp, pls, figs, tables, refs. Price £15.43 (paper, post-free).*

Of the 25 papers presented in this volume the following treat with metallurgy:

Over 7000 isoprobe analyses of silver-based coins are reported by R E M Hedges & D R Walker. 300 Roman brooches from Richborough subjected to atomic absorption analysis by J Bayley, S Butcher & I Cross revealed some significant variations in composition. Material from the Gussage All Saints bronze foundry has been studied by emission spectroscopy and metallography to reveal many manufacturing details (Spratling *et multi alii).*

The isotropic composition of lead in Greek coins and in Greek and Turkish silver/lead sources reported by V E Chamberlain and N H Gale. Chemical studies of Greek silver coins from the Asyut Hoard by P A Schubiger, O Muller and W Gentner, and a paper dealing with the use of trace element analysis to determine the provenance of copper artifacts by J D Muhly, T S Wheeler and R Maddin. PTC

Industrial Archaeology Kilns and furnaces. *Veszprem, 1981.*

Conference proceedings in industrial archaeology in Hungary entitled Archaeological and interdisciplinary researches on kilns and furnaces, Sopron, 1980. From the contents:

J Gomori: On the problem of early Medieval iron smelting furnaces and split iron pigs, *109-121.*

Early medieval bloomery furnaces in Hungary are divided into four types: Nemesker, Imola, Vasvar, Sopron. Stone-walled furnace at Kanyaszurdok near Sopron. Late Roman finds of heavy (50 kg) iron blooms with splits (presumably 5th century AD).

N Venclova: Early La Tène and Roman Period iron production at Lodenice and Svaty Jan pod skalou. *Archeologicke rozlhedy, 1982,* **34**, *3-23. (In Czech).*

Excavations in the area of the village Svaty Jan pod Skalou, carried out in 1978 led to the discovery of a furnace bottom of the Roman period. This had a flat hearth of about 60 cms and clay wall fragments indicated the existence of a former shaft superstructure. Early La Tène settlement finds nearby also contain fragments of bloomery slag, which indicate that there was a longer tradition of iron smelting in this iron-ore environment. CPSA

A P Zhuravlev, E I Devyatova and E L Vrubevskaya: Copper artifacts from the Zalavruga IV site. *Sov Ark 1981,* **4**, *247-249 (in Russian).*

A metallographic examination of early copper objects from Karelia. Pure copper plus cuprous oxide work-hardened to 95 HV. RFT

M Slivka: Medieval iron metallurgy and blacksmith's work in Eastern Slovakia. *Historica Carpathica, 1980,* 11, *218-288. In Czech.*

For the first part of this paper see *JHMS 1980,* 14, *(1).* This part deals with medieval iron weapons, armour, and fittings as represented in East Slovakian sources. CPSA

N.V Ryndina and L V Konkova: On the origin of large Usatovo daggers. *Sov Ark 1982 (2), 30-42.*

Late Tripolyan of the North West Black Sea region; can be equated to Early Minoan I and Middle Minoan I-II periods. Composition, structure etc favour West Anatolia as origin. Metallographic structures are shown but general analyses indicate copper-arsenic alloys only. Stone mould. RFT

M Slivka: Metallurgy of iron and the blacksmith's work in Eastern Slovakia. *Historica Carpatica, 1981,* 12, *211-276. In Czech.*

Discusses craftsmen's tools (tongs from Oborin and Saris, 11th-12th centuries, hammers from Saris), agricultural implements, structural iron and minor objects. The survey ends with consideration of some art objects. CPSA

V Rychner: LBA copper and copper alloys in West Switzerland. *Musée Neuchatelois, 1981,* 3, *97-124. (In French).*

A set of 84 bronze objects from a site of the Urnfield period in Auvernier/Nord (Late Ha B) has been submitted to a quantitative spectrographic analysis. The existence of a very homogeneous metallurgy has been proved, in the caster's method (tin, lead) as well as in the basic material used.

Another set of 11 objects from Neuchatel/Le Cret (early Ha B) also shows a large homogeneity. They are, however, different from those from Auvernier not only in their tin and lead alloy but also in the amount of their impurities. Author

J Schneider – H Stahlhofen: Two bloomeries in the Altmark and in the Borde. *Vom Faustkeil bis zur Kaiserpfalz, 25 Jahre Bodendenkmalpflege im Bezirk Magdeburg (J Schneider ed). Magdeburg, 1980, 53-54. (In German).*

Six bloomery furnaces, apparently of the slag-pit type, at Jeetze, Kr Kalbe/Milde, Late La Tène – Early Romano-Barbarian; a bi-pyramidal iron bar at Wopel; another bloomery furnace at Osmarsleben, now Gusten-Ost, Kr Stassfurt, undated. CPSA

I Serning: Grop-schaktungnen fran Hallfrede i Follingbo. Arkeologi pa Gotland. *Gotlandica, 1979,* 14, *173-178. In Swedish.*

A secondarily excavated slag-pit furnace was believed to be of the Migration Period, but radiocarbon analysis indicated the surprisingly earlier date of 380 BC - 75 AD. CPSA

T Stech-Wheeler, J D Muhly, K R Maxwell-Hyslop and R Maddin: Iron at Taanach and Early Metallurgy in the Eastern Mediterranean. *American Journal of Archaeology, 1981,* 85 *,245-265.*

Metallographical examination of a group of 10th century BC iron objects from Taanech, Palestine. A special technique using the scanning electron microscope allowed traces of pearlite or cementite to be detected in completely corroded specimens. Many of the 16 specimens investigated (sword, sickle plough-share, scale-armour, chisels, other blades), reveal in the author's opinion, deliberate surface carburizing. Preliminary reports on investigation of objects from Tel Qasile, Tell Hemmeh, Tell Fara South. These are against the hypothesis of a supposed monopoly of the Philistines in iron smelting. CPSA

ASIA

Han Bing-Gao: Casting in Ancient China. *Foundry Trade Journal, 1982,* 152*,(3231), 172-7.*

The author is president of the Peking Branch of the Foundry Institute of the Chinese Mechanical Engineering Society. In this well-illustrated article, the achievements of the bronze-age are outlined, including an 875 kg ritual food vessel cast nearly 3,600 years ago, a set of 64 small bells cast in 400 BC and the 46.5 ton Great Bell of Peking, cast nearly 500 years ago. Ancient founders used helmet-like open crucibles made from pottery for melting the metal. The earliest moulds were carved clay, often incorporating as many as ten or more components. Small parts such as ears were usually cast first and afterwards fitted into the main mould to be incorporated into the main casting. Lost wax casting was first introduced about 2,500 years ago. A document approximately 2 500 years old contains formulations for the manufacture of various types of implement. Of special interest is the composition of the six ingredients or component parts used in the manufacture of bronze castings.

The Iron Age is thought to have originated at the time of the Eastern Zhou Dynasty (770-256 BC). Hoes, ploughshares, picks, hammers, sickle blades, and arrowheads were commonly cast in iron. Malleable iron was used from an early date. Iron moulds for gravity diecasting, thought to date from the period 447 to 221 BC have been discovered. A cast-iron lion at Cangzhu, made in AD 953, weighs about 100 tons, and a 5 m high figure of a guard, made in iron at Taiyuan, exhibits no corrosion whatever, despite exposure to air for 1000 years. During the Quing Dyasty, one iron plant was equipped with 80 blowers each operated by 13 people, indicating a workforce in excess of 1000 men. APG

G Weisgerber: More than copper in Oman, Preliminary report on the Oman expedition of the German Mining Museum in 1981. *Der Anschnitt, 1981,* 33, *pp 174-263.*

New results on the medieval Islamic and the Makan period (3rd millennium BC) copper production in Oman. From the excavations at the copper smelting site of Maysar-1, beside new single fragments of Bronze Age copper ingots a hoard of bun-shaped ingots or fragments was found. 22 pieces weighing 6 kg in total were deposited in a shallow hole between three hearths beside which were the moulds into which the refined copper was probably poured, to form the bun-shaped ingots. A 3rd millennium BC small ingot of copper matte from Bilad al-Maaidin proves again the smelting of sulphidic ores at this time.

For the first time it has been proved that besides copper, chlorite ('steatite') was also exploited and exported in the Gulf. Strong evidence for connections to the Indus valley civilizations also are reported. Author

Hua Jueming: Research on Han Wei Spherical Graphite Cast Iron. *In Abstracts of 16 World Conference of Science and Technology History, 1981, 16 pp.*

This paper describes research, based on modern testing means, on the graphite appearance and structure of the iron pick of the Western Han dynasty unearthed in Tieshenggou, Gong county, and of the Han Wei iron axe unearthed in Mianchi, confirming that these iron wares have spheroidal graphite with uniform distribution, produced by annealing.

The foregoing research result confirms that spheroidal graphite cast iron appeared as far back as 2000 years ago. The appearance and mechanical properties of the graphite are similar with that of modern spheroidal graphite cast iron, reaching Grade 1-2 of the spheroidal graphite cast iron metallographic standard. The authors also made a heat treatment test on the Han Wei hypereutectic white cast iron share with low silicon, high carbon, and produced a large amount of graphite nodules with uniform distribution, and good roundness.

D B Wagner: The Han iron industry. Paper presented to the symposium: *China's past unearthed: the reconciliation of the new discoveries and the historical records of the early Imperial period. San Francisco, March 26-28, 1980. 109 pp.*

There is a very extensive review of archaeological finds from the period 471 BC to 220 AD, and the results of metallographic examination of a number of artefacts are discussed. During the Han period (206 BC - 220 AD) only swords and knives were produced from wrought iron (presumably made by the bloomery process). A very wide range of artefacts have been found which were made from grey cast-iron, white cast-iron, decarburised white cast-iron, and malleablised white or grey iron. Enough coal has been found at Han ironworks to assure us that it was used in some process, but no firm conclusions can be drawn about its use for smelting. The very early discovery of cast iron seems to be the direct result of early large-scale iron production, and rapid development would be facilitated by experience gained in making large bronze castings.

Detailed consideration is given to the furnaces and equipment used and the methods of operation. Coal largely replaced charcoal in iron smelting by the end of the Song period (960-1279 AD).

R Maddin, J D Muhly, T Stech-Wheeler: Research at the Center of Ancient Metallurgy. *Palorient, 1981,* **6**, *111-1191.*

Survey of research activities in non-ferrous and ferrous palaeometallurgy in Turkey, Cyprus, Syria, Palestine and Iraq. CPSA

T H Maugh II: A Metallurgical Tale of Irony: Two Stanford investigators studying superplastic metals rediscover the secret of manufacturing Damascene steel. *Science 215, 1982, 153.*

A rather journalistic report of studies carried out on wootz steel and Damascene blades in connection with the work of *J Wadsworth* and *O D Sherby* Also see critical reply of C S Smith, *Science, 1982, 216, 242-4* (Abstracts edition). CPSA

AMERICA

R Dirscherl. Ead's Bridge Pioneered New Era in Steel Usage. *Metal Progress, December 1981,* **120** *(8), 28-33.*

Opened 4th July 1874, the bridge spans the Mississippi River at St Louis and is the first arched steel truss bridge in the world, and the first to require alloy steel for essential components. Recent analysis of the staves shows 0.53%C, 0.2%Mn, 0.4%Cr, 0.12%Si, 0.02%S balance iron: hardness 195-250 HB.

As a result of the tests, Eads became convinced that it was possible to obtain crucible steel in small bars of the desired quality and elected to use tubes fabricated from rolled bars and stiffened by internal staves for the support arches. APG

S M Epstein: A Coffin Nail from the Slave Cemetery at Catoctin, Maryland. *Masca Journal, 1981,* **1** *(7), 208-210.*

A metallographic section of the nail shows fine grained ferrite with iron silicate slag stringers in the outer zone of the shaft, and hypoeutectoid steel with an embryonic Widmanstatten structure on the axis. No spheroidization of the cementite was detected. This is consistent with the use of nail rod made from decarburised pig iron, the heated rod being hand forged to the shape of the nail without intermediate reheating. APG

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

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Cover illustration

As the contribution from L S Chuang, L W Kwong and Y C Wong is the first article from the Far East received for publication in JHMS, it was thought appropriate to use as the cover illustration for Volume 17, a drawing showing ancient Chinese hydraulic equipment.

This shows water-wheel operated trip-hammers which are known to have operated from the 1st century AD. This particular drawing shows a vertical wheel working hammers removing the husk from cereal grains and is from the Thien Kung Khai Wu (1637). Acknowledgement is made to Joseph Needham's Dickinson Memorial Lecture given to the Newcomen Society on May 9th 1956.

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

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