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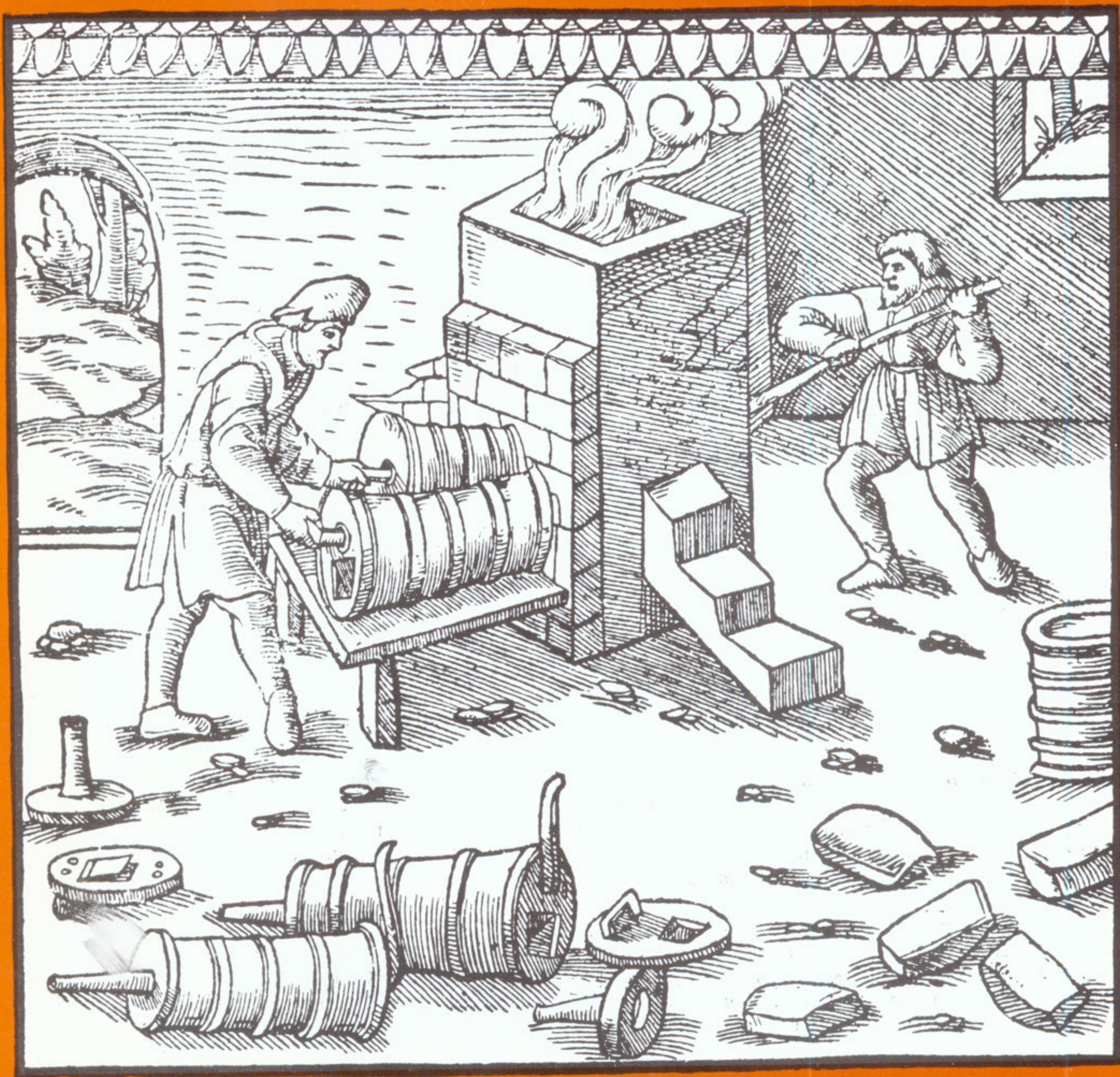

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Contents

Cover Illustration: In this issue Bryan Earl continues his investigation into tin melting in the West of England. From time to time he mentions furnaces depicted in Agricola (De Re Metallica) and in Book IX (page 419 in the Hoover edition) there is a drawing showing a small furnace used by the Lusitanians (ancient Lusitania comprised Portugal and parts of Spain) for melting tin from tin-stone.

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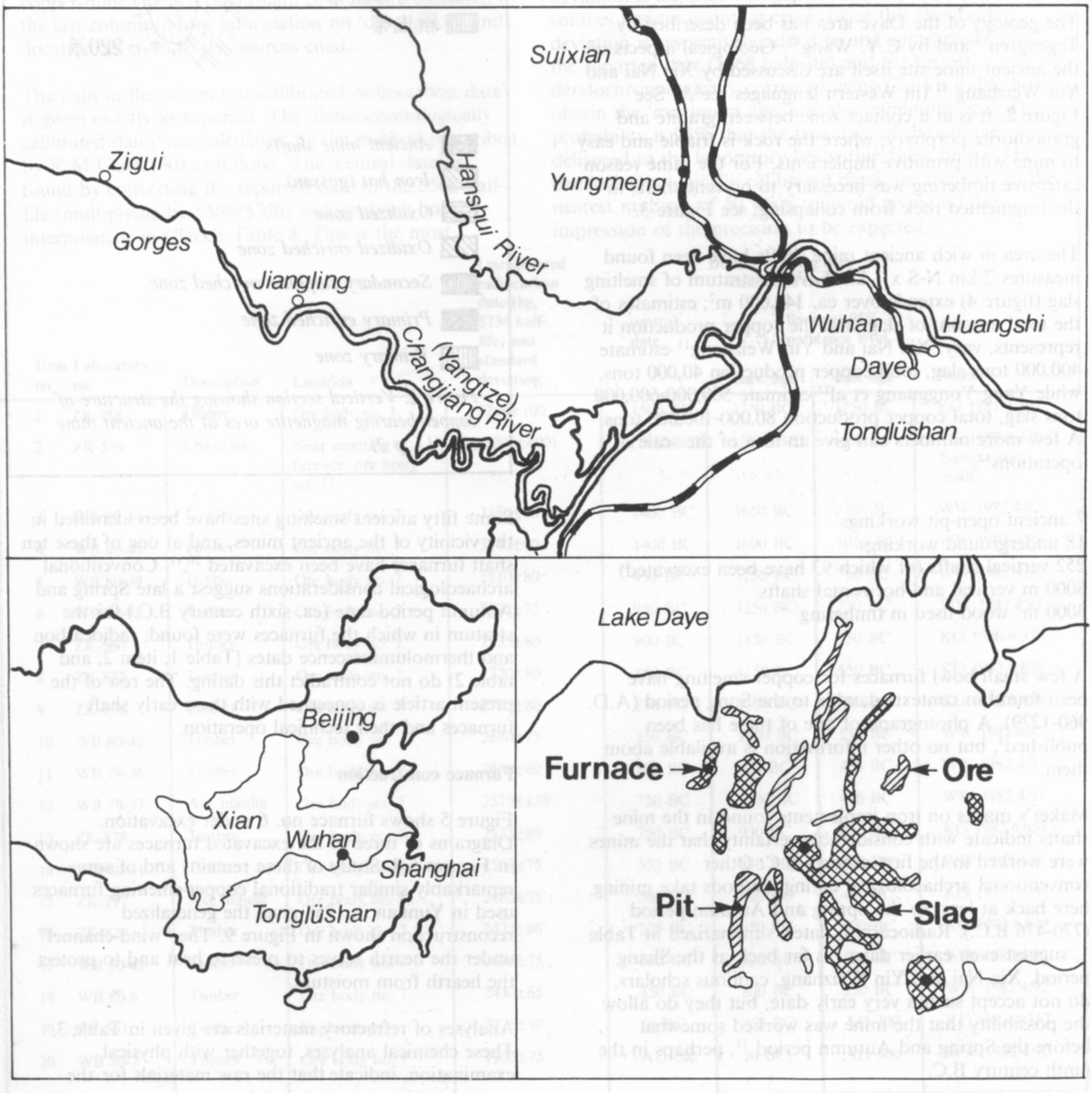
Ancient Chinese copper smelting, sixth century BC: Recent excavations and simulation experiments

Edited and translated by D B Wagner

Excavations at the ancient copper-mine site at Tonglüshan in Daye County, Hubei, have in recent years produced a great wealth of new material concerning ancient Chinese mining and smelting techniques. The present article describes recent work on ten copper-smelting shaft furnaces found here.

The mine site

Daye has long been an important site of iron and copper production. The Swedish geologist F.R. Tegengren visited the area in 1915 and saw "ruins of old smelters and vast heaps of slag", which he estimated at



several hundred thousand tons[33]. In modern times Daye has been better known for its iron production, and Tegengren, noting that the ancient slag contains as much as 51.5% iron, concluded that the ancient smelting methods were fantastically inefficient. Modern work shows that the slag is actually from copper smelting, flaxed with iron oxides.

The location of Tonglüshan can be seen on the map, Figure 1. Modern open-pit mining operations began here in 1965. Numerous ancient mine shafts were discovered, but these seem to have been ignored until the discovery of a bronze axehead in 1973 made it clear that the shafts were much more ancient than had been thought. Excavations were undertaken by the Hubei Provincial Museum in 1974 and by the Institute of Archaeology, Chinese Academy of Social Sciences, in 1979-80.

The geology of the Daye area has been described by Tegengren[33] and by C.Y. Wang[37]. Geological aspects of the ancient mine site itself are discussed by Xia Nai and Yin Weizhang [11] (in Western languages see[1],[4]). See Figure 2. It is at a contact zone between granite and granodiorite-porphyry, where the rock is friable and easy to mine with primitive implements. For the same reason extensive timbering was necessary to prevent shafts in the fragmented rock from collapsing; see Figure 3.

The area in wich ancient mine shafts have been found measures 2 km N-S x 1 km E-W. A stratum of smelting slag (figure 4) extends over ca. 140,000 m^2; estimates of the total amount of slag, and the copper production it represents, vary. Xia Nai and Yin Weizhang[11] estimate 400,000 tons slag, total copper production 40,000 tons, while Yang Yongguang et al[12] estimate 500,000-600,000 tons slag, total copper production 80,000-100,000 tons. A few more numbers can give an idea of the scale of operations[12].

7 ancient open-pit workings
18 underground workings
252 vertical shafts (of which 93 have been excavated)
8000 m vertical and horizontal shafts
3000 m^3 wood used in timbering

A few small bowl furnaces for copper smelting have been found in contexts datable to the Song period (A.D. 960-1279). A photograph of one of these has been published[3], but no other information is available about them.

Maker's marks on iron implements found in the mine shafts indicate with considerable certainty that the mines were worked in the first century B.C. Other conventional archaeological dating methods take mining here back at least to the Spring and Autumn period (770-476 B.C.). Radiocarbon dates, summarized in Table 1, suggest even earlier dates, as far back as the Shang period. Xia Nai and Yin Weizhang, cautious scholars, do not accept such a very early date, but they do allow the possibility that the mine was worked somewhat before the Spring and Autumn period [11], perhaps in the ninth century B.C.

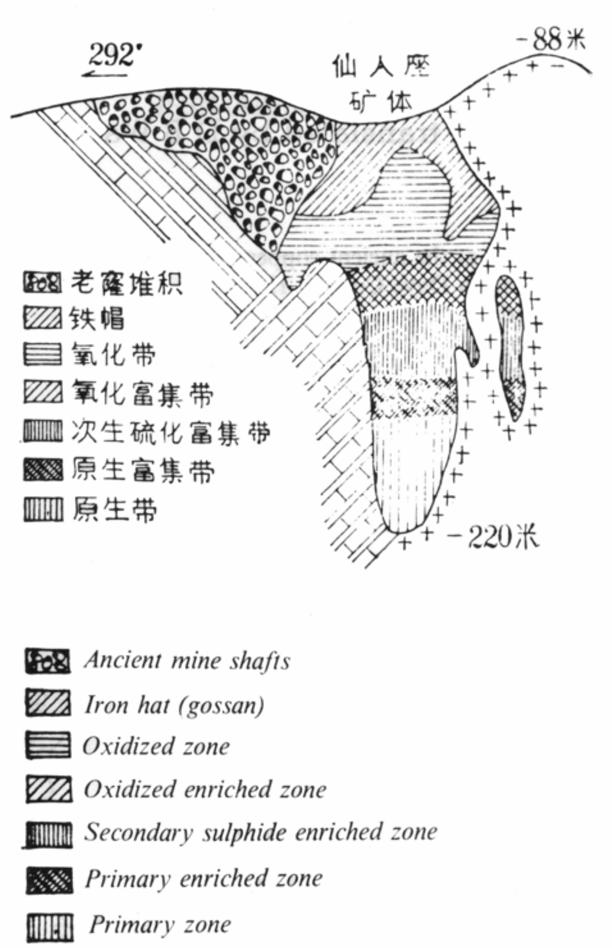


Figure 2. Vertical section showing the structure of copper-bearing magnetite ores at the ancient mine site (11, p 2).

Some fifty ancient smelting sites have been identified in the vicinity of the ancient mines, and at one of these ten shaft furnaces have been excavated [20],[11]. Conventional archaeological considerations suggest a late Spring and Autumn period date (ca. sixth century B.C.) for the stratum in which the furnaces were found; radiocarbon and thermoluminescence dates (Table 1, item 2, and table 2) do not contradict this dating. The rest of the present article is concerned with these early shaft furnaces and their technical operation.

Furnace construction

Figure 5 shows furnace no. 6 under excavation. Diagrams of three of the excavated furnaces are shown in Figures 6-8. Study of these remains and of some remarkably similar traditional copper-smelting furnaces used in Yunnan in 1958 gives the generalized reconstruction shown in Figure 9. The "wind-channel" under the hearth serves to preserve heat and to protect the hearth from moisture.

Analyses of refractory materials are given in Table 3. These chemical analyses, together with physical examination, indicate that the raw materials for the refractories were: kaolin (china clay); a local red clay whose principal constituents are kaolinite and iron oxides; pieces of iron ore; iron-ore sand (sieve tailings); quartz sand; and stones. For the different parts of the furnace different mixtures of these materials were used. For example the base was made of a mixture of red clay, stones, pieces of iron ore, and iron-ore sand, while the furnace lining was made of kaolin and quartz sand.

Furnace charge

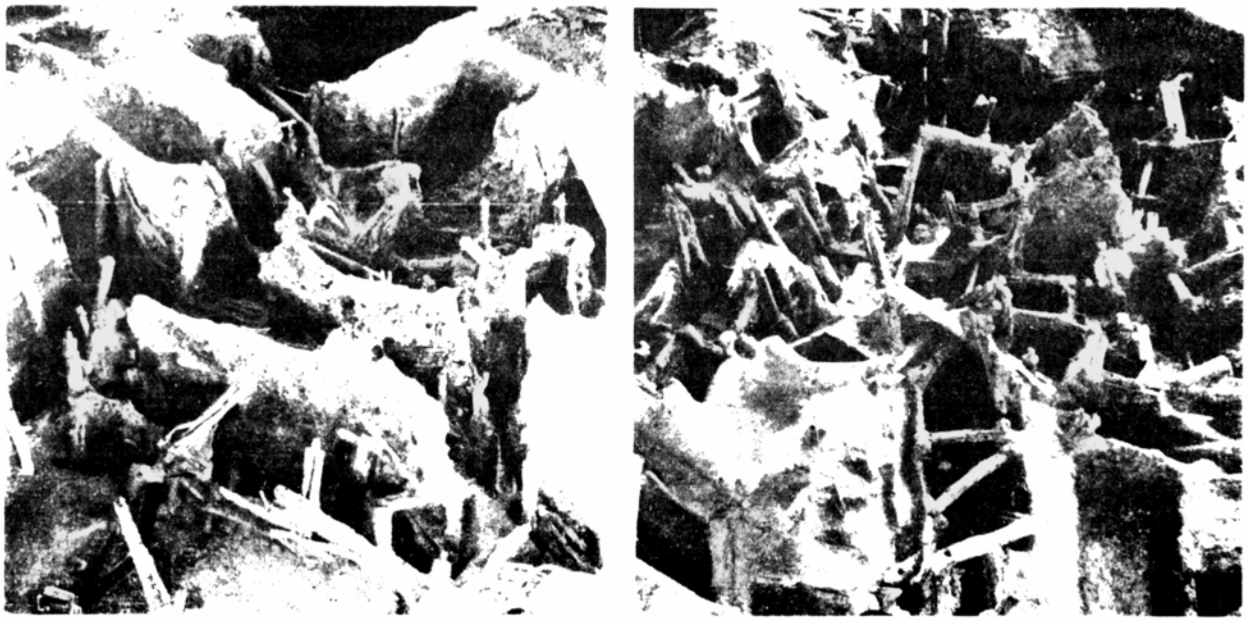
The principal ore minerals found in the ancient workings at Tonglüshan are[22,21]:

chrysocolla, $CuSiO_3.2H_2O$	andradite, $3CaO.Fe_2O_3.3SiO_2$,
malachite, $CuCO_3.Cu(OH)_2$	$Cu_3(AlSi_3O_{10})(OH)_2.nH_2O$
azurite, $2CuCO_3.Cu(OH)_2$	native copper, Cu
magnetite, Fe_3O_4	cuprite, Cu_2O
haematite, Fe_2O_3	tenorite, CuO

Table 1 Available radiocarbon dates from the ancient copper-mine site at Tonglüshan. Sources are indicated in the last column. More information on 'description' and 'location' is given in the sources cited.

The data in the column 'uncalibrated radiocarbon date' is given exactly as reported. The 'dendochonologically calibrated dates' are calculated by the method prescribed by R M Clark (30) as follows. The 'central date' is found by converting the reported date to the 5568 half-life (multiplying by 5568/5730) and applying linear interpolation in Clark's Table 8. This is the most probable date for the sample. The reported standard deviation is adjusted upward to account for other error sources besides counting error; twice this standard deviation is respectively added to and subtracted from the reported date (5568 half-life) and the results dendochronologically corrected using Clark's Table 8 to obtain the 'maximum age' and the 'minimum age'. The probability is 95% that the true date of the sample delivered to the laboratory lies within these limits. The dendochronologically calibrated dates are rounded to the nearest multiple of 50 years to avoid giving a false impression of the precision to be expected.

Item no.	Laboratory no.	Description	Location	Uncalibrated radiocarbon date (bp, 5730 half-life) and standard deviation	Dendochronologically calibrated date: central date	limits at 95% confidence level: max. age	min. age	Notes
1	ZK-758	Timber	Ore body no. 7	3260±100	1500 BC	1750 BC	1250 BC	KG 1981.4:367
2	ZK-559	Charcoal	Near smelting furnace, ore body no. 11	(3205±400)	(1450 BC)	(2500 BC)	(450 BC)	KG 1980.4:376 'Sample too small'
3	WB 80-44	Timber	Ore body no. 7	3150±80	1400 BC	1650 BC	1100 BC	WW 1982.4:92
4	WB 80-40	Timber	Ore body no. 7	3140±80	1400 BC	1600 BC	1050 BC	WW 1982.4:92
5	WB 80-39	Timber	Ore body no. 7	2810±80	950 BC	1250 BC	750 BC	WW 1982.4:92
6	WB 79-35	Timber	Ore body no. 7	2795±75	950 BC	1250 BC	750 BC	WW 1982.4:91
7	ZK-560	Timber	Ore body no. 7	2735±80	900 BC	1150 BC	550 BC	KG 1980.4:376
8	ZK-877	Timber	Ore body no. 7	2720±80	850 BC	1150 BC	550 BC	KG 1982.6:659
9	ZK-876	Timber	Ore body no. 7	2705±80	850 BC	1100 BC	500 BC	KG 1982.6:659
10	WB 80-42	Timber	Ore body no. 7	2680±75	850 BC	1000 BC	550 BC	WW 1982.4:92
11	WB 79-36	Timber	Ore body no. 7	2600±80	800 BC	950 BC	450 BC	WW 1982.4:91
12	WB 79-37	Axe handle	Ore body no. 7	2575±135	750 BC	1000 BC	400 BC	WW 1982.4:91
13	ZK-878	Timber	Ore body no. 7	2575±80	750 BC	900 BC	450 BC	KG 1982.6:659
14	WB 80-41	Timber	Ore body no. 4	2500±75	550 BC	850 BC	400 BC	WW 1982.4:92
15	ZK-297	Axe handle	Ore body no. II	2485±75	500 BC	850 BC	400 BC	KG 1977.3:202-3
16	ZK-879	Timber	Ore body no. 7	2475±80	500 BC	850 BC	400 BC	KG 1982.6.659
17	WB 80-43	Timber	Ore body no. 7	2470±75	500 BC	800 BC	400 BC	WW 1982.4:92
18	WB 80-6	Timber	Ore body no. 7	2430±65	450 BC	800 BC	250 BC	WW 1982.4:92
19	ZK-561	Timber	Exploration	2075±80	50 BC	350 BC	AD 200	KG 1981.4:367
20	WB 80-7	Timber	Ore body no. 7	1905±75	AD 200	50 BC	AD 300	WW 1982.4:92



1. 一组完整的井巷   2. 在掘面上纵横交错的古巷道

Figure 3. Ancient mine shafts under excavation (11, plate 2.1-2).

The ancient workings are all in the oxidized zone; therefore sulphide ores were not encountered. Chemical analyses of some ore samples are given in Table 4. (More analyses of iron ores are given by Tegengren[33]. A basketful of rich malachite ore was found in the mine (photograph in [3], so the especial value of these ores was apparently recognised. However broken-up chunks of leaner ore, diameter 3-4 cm, were found in pits near furnace no. 10. It is apparent that a mix of ores of different categories was charged.

Table 2 Thermoluminescence dates for refractories from furnaces (17, p. 550; cf. 18)

sample no.	location	age years	laboratory error years
TK11-1	inner wall, furnace no. 1	1830	±210
TK11-2	do.	2447	±240
TK11-3	do.	2278	±205
TK12	base, furnace no. 1	2374	±142
TK14-1	wall, furnace no. 2	1877	±153
TK14-2	do.	1769	±162
TK14-3	do.	1913	±189
TK17	wall, furnace no. 3	2856	±295
TK67	wall, furnace no. 10	3014	±320
TK68	tapping arch, furnace no. 10	2895	±305

Limestone is widely distributed in the vicinity, and in the simulation experiments (described below) a limestone flux was used. There is, however, no evidence that limestone was charged in the ancient furnaces. An analysis of the local limestone was published by C.Y. Wang in 1917[37]:

SiO_2	$Al_2O_3Fe_2O_3$	CaO	MgO	sp.gr.
3.14	1.14	52.63	0.92	2.71

(thus $CaCO_3$ 93.86%, total 99.06%).

There is no doubt that the fuel used was charcoal. No analyses have been published for the charcoal found on the site.

Furnace output

Table 5 gives analyses of two pieces of raw copper found in the ancient furnaces. These should be closely representative of the actual product of the furnaces. The copper ingot analysed in Table 6 was not found in a dateable context, but it may very well be from the same time as the furnaces. The axehead analysed in Table 6 was found in an ancient mine shaft, so it is likely to be of the same time; the relatively high iron content suggests that it may have been cast from the locally-produced copper.

Three reports of slag analyses are given in Tables 7-9. It can be seen that some rows in each table are also found in one or both of the others, but that some rows in each table are unique. A few typographical errors (none of which affects the order of magnitude) can be detected. To these may be added Tegengren's analysis of a single slag sample[33]:

Silica	23.63%	
Ferrous iron oxide	60.00%	Metallic iron 51-5%
Ferric iron oxide	6.90%	
Phosphoric acid	0.33%	

"These items make up a total of about 91%; the remaining 9% consist of lime, alumina, magnesia and manganese."

Some results of the phase analysis of slag smaples are given in Table 10. Melting points of various samples were in the range 1334-1449° C in air and in the range 1100-1200° C in argon. Fayalite (Fe_2SiO_4) is produced by the combination of silica (SiO_2) and wüstite (FeO) above 1270° C, so the slag must have been above this temperature at some point in the smelting process[21]. Copper with 3-4% iron has a melting point (liquidus) in the range 1100-1200° C, and it seems reasonable to estimate the hearth temperature at 1200-1300° C.

Furnace operation

Reduction of the various copper compunds to metallic copper should be straightforward in this furnace; the essential technical problem is to produce a free-flowing slag. The ore analyses (Table 4) show that silica and iron oxides are by far the most important components of the gangue, and the slag analyses (Tables 7-10) indicate that the strategy adopted was to use a mix of ores of different compositions such that a slag was produced whose principal component is fayalite (Fe_2SiO_4). In fayalite the weight ratio SiO_2/Fe is 0.54; in nearly all the slag samples this ratio is between 0.5 and 1.0, with a mean of about 0.7. In the ore analyses in Table 4 the ratio ranges between 0.23 and 7.7; thus an appropriate mix of these ores could give the required ratio in the slag.

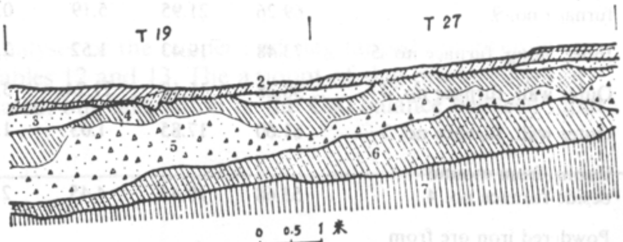


Figure 4. Section of the strata near the ancient smelting site (20, p 30). The scale shows 1 m. 1. Modern accumulation of earth mixed with iron ore, thickness 0.05-0.35 m. 2. Disturbed surface stratum of grey-brown earth mixed with a small amount of slag, thickness 0.15 m. 3. Black limy soild mixed with a small amount of slag, thickness 0.05-0.35 m. 4. Grey-brown earth mixed with a large amount of slag, thickness 0.1-0.6 m. 5. Red-brown and grey-brown earth mixed with a large amount of slag and fragments of red-fired clay, thickness 0.15-1.2 m. 6. Red clay mixed with a small amount of slag, fragments of re-fired clay, magnetite ore, malachite, and charcoal, thickness 0.25-0.9 m. 7. Natural alluvial soil.

Figure 5. Furnace no 6 under excavation (3, p 19; cf. 22, p 63). Slag accumulation in background.

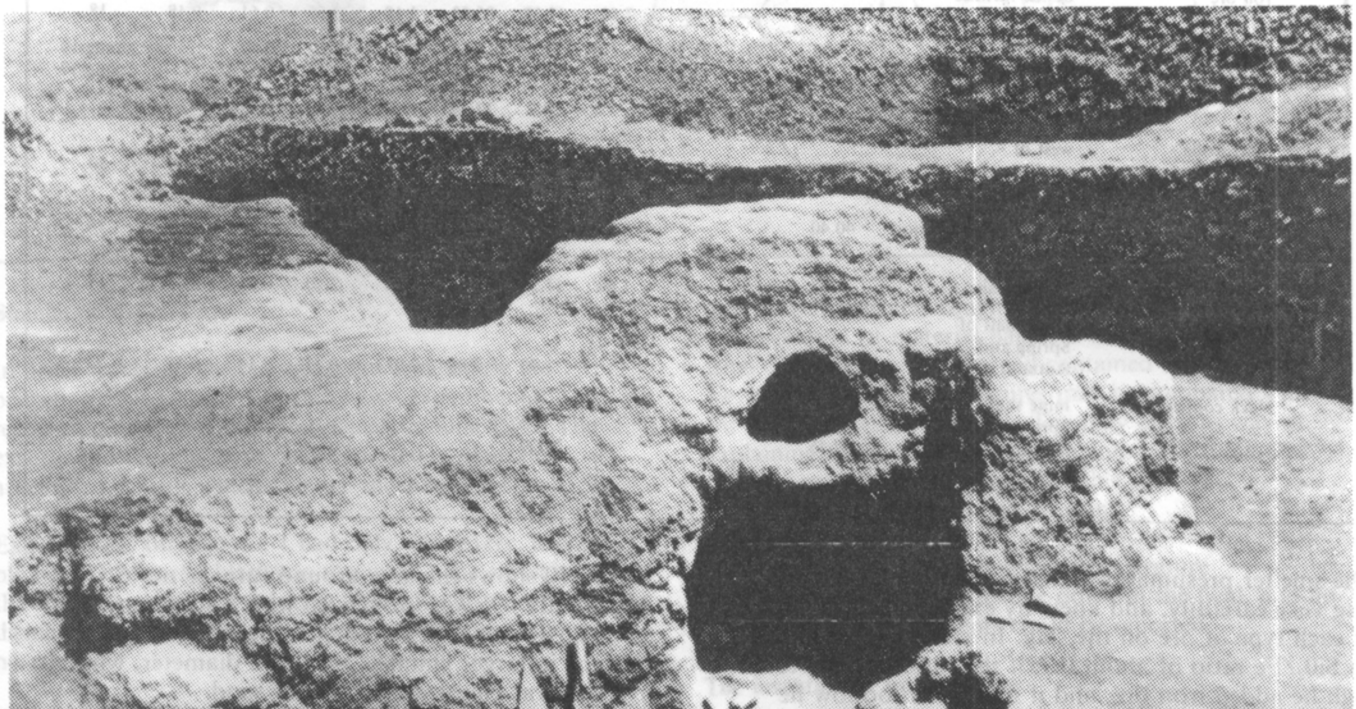


Table 3 Analyses of refractories (21, p. 159)

Sample location	principal chemical constituents % SiO_2	Al_2O_3	Fe_2O_3	Cao	MgO	Na_2O	K_2O	TiO_2	refrac-toriness °C	sample no.
Lining of upper part of tapping arch, furnace no. 4	76.67	18.35	4.04	0.16	—	0.034	0.51	0.35	1580	6
Lining of upper part of tapping arch, furnace no. 5	72.43	18.68	4.75	0.48	—	0.035	0.66	0.44	1580	8
Penultimate layer of furnace wall, furnace no. 9	69.26	21.95	5.19	0.28	—	0.043	0.70	0.56	1610	7
Inner lining, furnace no. 5	73.48	19.43	1.52	2.20	0.26					nai-16
Outer wall, furnace no. 4	38.28	15.10	21.24	3.78	1.32					nai-21
Outer wall, furnace no. 5	61.60	17.85	1.03	1.93	0.43					nai-24
Kaolin from mound beside furnace no. 4	53.68	19.43	4.45	2.27	0.86				1370	nai-22
Powdered iron ore from mound beside furnace no. 6	30.36	6.647	28.04	0.42	1.59					kuang-25

Table 4 Analyses of some ore samples (21, p. 162)

cate-gory	designation	location	principal constituents Cu	FeO	Fe_2O_3	Fe	SiO_2	CaO	Al_2O_3	MgO	S	no.	sample
III	malachite	beside furnace no. 8	53.2	0.51	0.43			3.52	0.29	0.33			kuang-23
I	iron ore	beside furnace no. 9	0.98			7.60	62.38	25.53	1.18	2.55	0.61	0.18	18
I	copper - iron ore	beside furnace no. 6	3.28	2.71	21.35			9.68	0.47	1.63	0.82		kuang-19
			2.059	3.33	18.85			17.60	1.22	1.37	1.51		kuang-17
		Tonglüshan	1.87				54.2	12.44	1.64	2.1	0.48		
II	chrysocolla	west of smelting site	20.34				6.34	48.83	0.23	10.72	0.42	0.59	20
		mine shaft of Western Zhou period	40.40			0.60	2.99	20.00	0.64	4.41	0.37	0.53	14
	iron ore with malachite inclusions	west of smelting site	31.88			1.40	17.29	15.72	1.27	2.50	0.22	0.53	19
III	malachite	mine shaft of Spring and Autumn period	51.82				1.90	2.88	0.073	0.77	0.14	0.57	23
	black copper ore	mine shaft of Spring and Autumn period	22.45				21.29						IV-1

The smelter presumably watched the condition of the slag very carefully, and knew by experience the effect of each type of ore on the slag. In effect he aimed for an SiO_2/Fe ratio of about 0.7; if the ratio became too high he added iron ore, and if it became too low he added ores which were high in silica and low in iron. Very rich ores such as malachite (ca. 50% Cu, 2% Fe, 3% SiO_2) do not seem to have been necessary for furnace operation, but obviously would have been desirable for reasons of efficiency.

Figure 10 shows the area around furnace no. 6. Apparently ore was broken up with a stone on a flat stone anvil and then sieved. The richer ores were charged in larger chunks, 3-4 cm in diameter, while iron ore was charged as gravel or sand.

Presumably the use of this smaller particle size was necessary to obtain an immediate effect when the slag began to freeze up because of an excess of silica, but it no doubt caused difficulties with the fine particles being blown out the furnace mouth.

Lu Benshan and Zhang Hongli[21] note that in traditional Chinese copper-smelting furnaces used in 1958 the weight of coke charged was generally 20-30% of the weight of ore, but was sometimes as high as 50%. The iron content of the raw copper from Tonglüshan is somewhat higher than from these later furnaces, and this suggests that the charcoal ratio may have been 50%. Assuming that the blast volume was m^3/min, that the ore charged was 24% copper on average, that recovery of copper was 95%, and that a limestone flux was not used, they calculate that production was ca. 353 kg per 24 hours. The details of this calculation are given in a forthcoming article[16] which I have not seen. The simulation experiments used a much leaner ore than this, and 100 kg of copper was produced in 10½ hours; this extrapolates to ca. 230 kg in 24 hours, and thus the calculation seems quite reasonable.

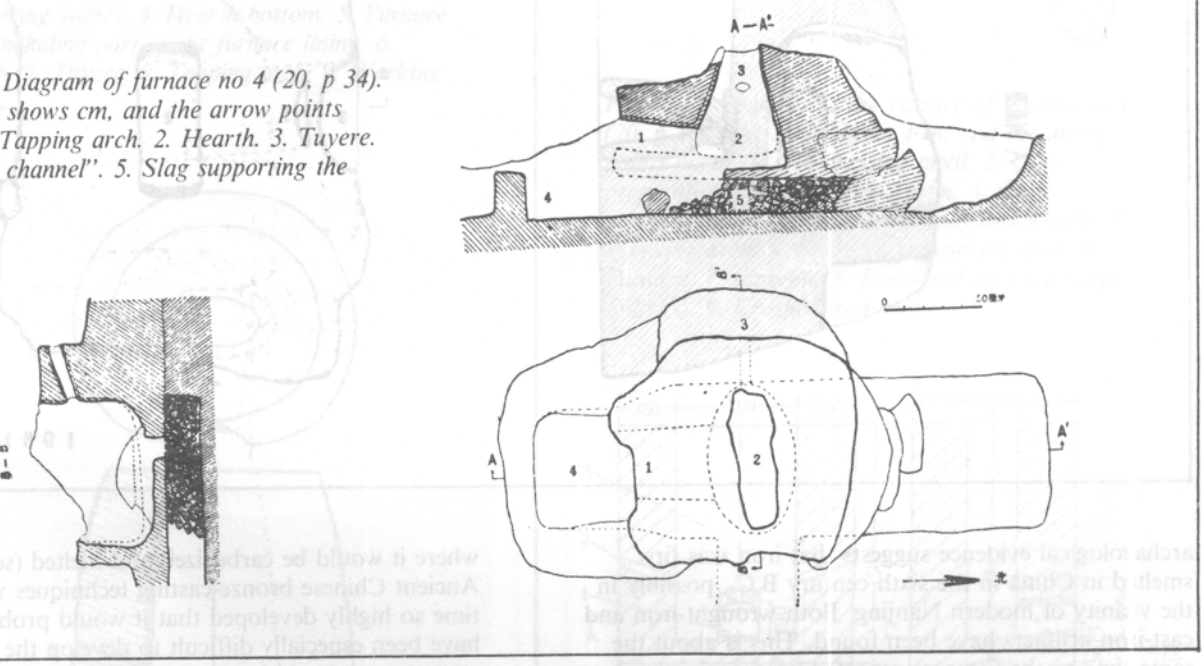


Figure 6. Diagram of furnace no 4 (20, p 34). The scale shows cm, and the arrow points north. 1. Tapping arch. 2. Hearth. 3. Tuyere. 4. "Wind channel". 5. Slag supporting the hearth.

Simulation experiments

In order to clarify various questions concerning the operation of the ancient furnaces two experimental reconstructions were built and tested in June 1980. The experimental results have been reported in several articles[16,19,21,22], of which [22] is the most detailed.

Experimental furnace no. 1 had only one tuyere, and the blower used for the blast was too weak. The result was tha the charge did not descend. When the furnace was dismantled 2 kg of metallic copper was found in the hearth.

Experimental furnace no. 2 was much more successful. Two different diagrams of the same furnace are shown in Figures 11 and 12; construction and operation are shown in Figures 13-16. The furnace was operated continuously for 10 hours 36 minutes. The blast was 4.5 — 5.0 m^3/min at a pressure of 122-130 mm water. The total charge was:

1002.5	kg	lean ore (analysis in Table 11)
100	kg	rich ore (no analysis given)
111	kg	quartz
122.5	kg	limestone
731	kg	charcoal

This was charged in 109 batches, i.e. about 10 batches per hour. Slag was tapped 14 times (opening only the upper part of the taphole) and copper was tapped twice. Copper output was 70 kg tapped and 30 kg remaining in the hearth.

Analyses of the copper and slag tapped are given in Tables 12 and 13. The amount of slag produced is not stated, but calculation of the Ca0 balance between input and output indicates roughly 700 kg slag. Further consideration of material balances then indicates that the total of 1102.5 kg ore charged contained 9% Cu, 23% Fe, and 10% Si0_2; these figures may be compared with the ore analyses in Table 11. The only obvious way of explaining the low calculated iron content is to assume that the samples analyzed in the table are unrepresentative with respect to iron.

Unfortunately the experimenters' temperature measurement equipment broke down in the field, and no temperature measurements could be reported.

The invention of iron-smelting

I am personally more interested in iron than in copper, and I have studied these copper-smelting furnaces because they may throw some light on the origin of iron-smelting in China. Presently-available

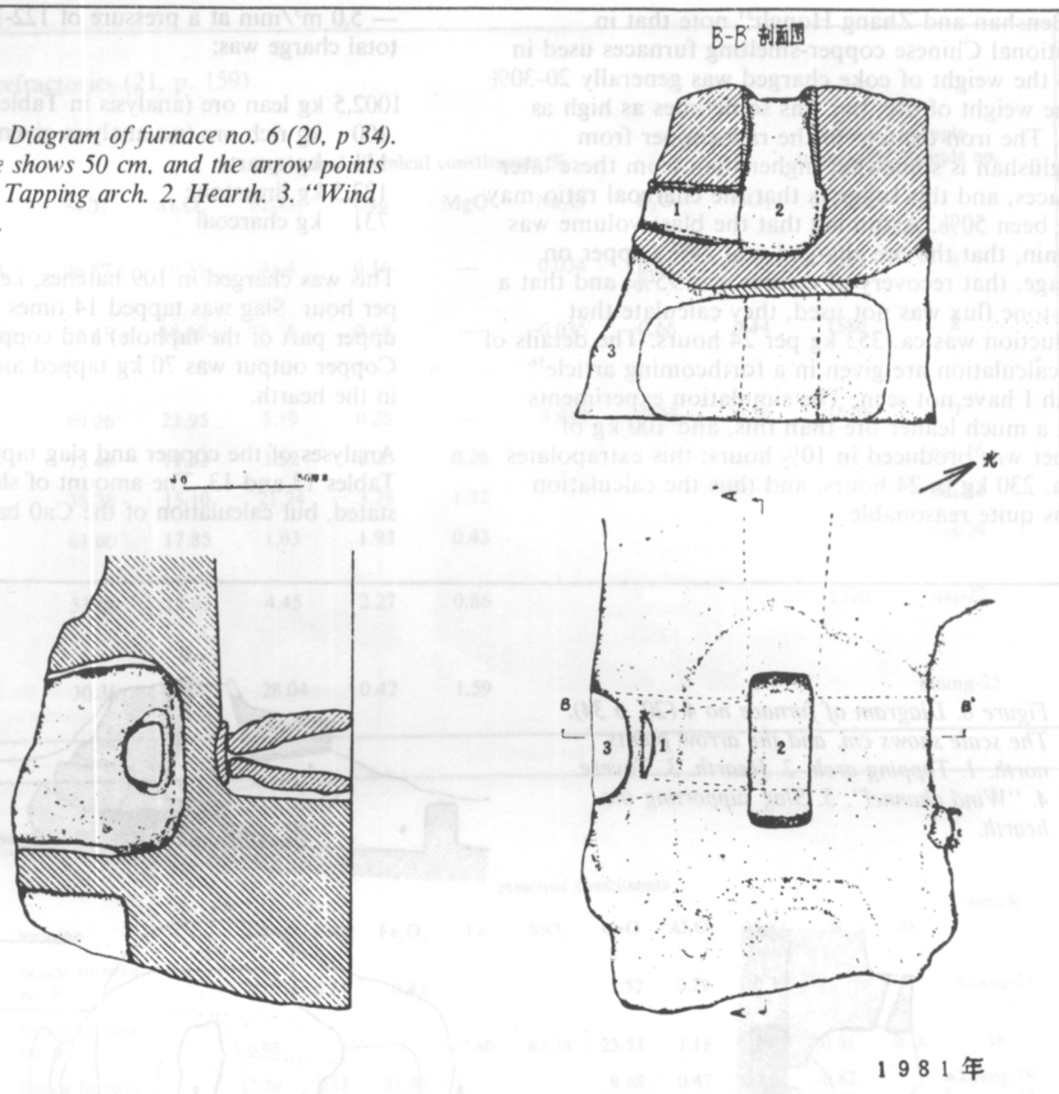


Figure 7. Diagram of furnace no. 6 (20, p 34). The scale shows 50 cm. and the arrow points north. 1. Tapping arch. 2. Hearth. 3. "Wind channel".

archaeological evidence suggests that iron was first smelted in China in the sixth century B.C., possibly in the vicinity of modern Nanjing. Both wrought-iron and cast-iron artifacts have been found. This is about the same time as the furnaces reported here, and only about 450 km to the north-east.

Under what conditions could a furnace like this be made to produce iron? It seems that all that was really necessary was a higher concentration of CO in the furnace atmosphere. Reduction of copper requires very little CO; reduction of Fe_2O_3 and Fe_3O_4 to FeO requires somewhat more, while reduction of FeO to Fe requires considerably more (see eg. [32]). Thus to produce metallic iron in this furnace, with the same ore charge and at the same operating temperature, all that was required was to increase the amount of charcoal charged, and possibly to decrease the blast.

The most likely result of initial experiments in this direction would be "bloom iron" with low carbon, left behind in the furnace unmelted. This could be worked by smiths in the usual way, or it could be charged in a cupola furnace of the type used for bronze-casting, where it would be carburized and melted (see e.g.[31]). Ancient Chinese bronze-casting techniques were by this time so highly developed that it would probably not have been especially difficult to develop the techniques necessary to cast this new metal into useful or decorative objects.

Enough is known about bloomery furnace operation (e.g. [34]) to make it clear that operating a furnace of this type as a bloomery furnace is a practical as well as a theoretical possibility. The next question is whether it could be made to function as a blast furnace which operates continuously and produces molten iron. There are two problems here. First, the iron must remain in a CO-rich atmosphere long enough raise its carbon content to ca. 4% (melting point ca. 1150° C). Second, a free-flowing slag must be produced. The second problem could be solved by using ores like those analyzed in table 11, with high iron content and fairly low silica (ca. 50% Fe, 8% SiO_2); with a loss of perhaps 10-15% of the iron in the ore a slag could be produced which resembles the copper-smelting slag. The first problem is more difficult to deal with theoretically, since it involves complex considerations of reaction kinetics.

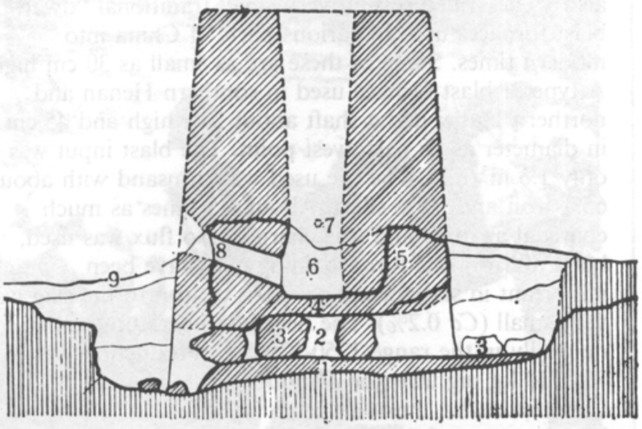


Figure 8. Diagram of furnace no 10 (11, p 9; also 15, p 19). 1. Foundation. 2. "Wind channel". 3. Supporting stones. 4. Hearth bottom. 5. Furnace wall, including part of the furnace lining. 6. Hearth. 7. Tuyere. 8. Tapping arch. 9. Working area.

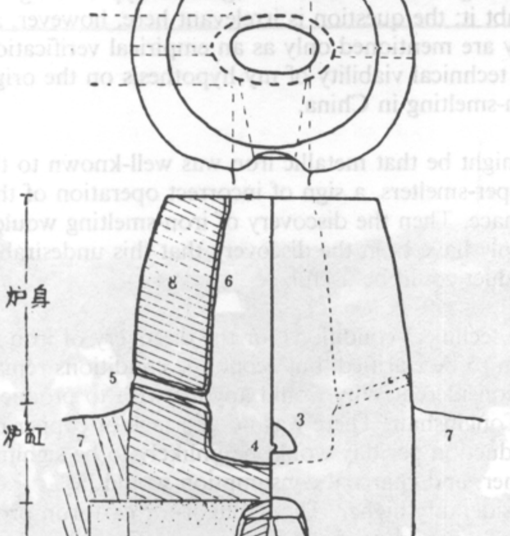


Figure 9. Generalized reconstruction of the ancient copper-smelting furnace (19, p 40). The scale shows cm. The three sections indicated on the left are, top to bottom: shaft, hearth, foundation. 1. Base. 2. "Wind channel". 3. Tapping arch. 4. Taphole. 5. Tuyere. 6. Inner lining. 7. Working area. 8. Furnace wall. 9. Ground surface.

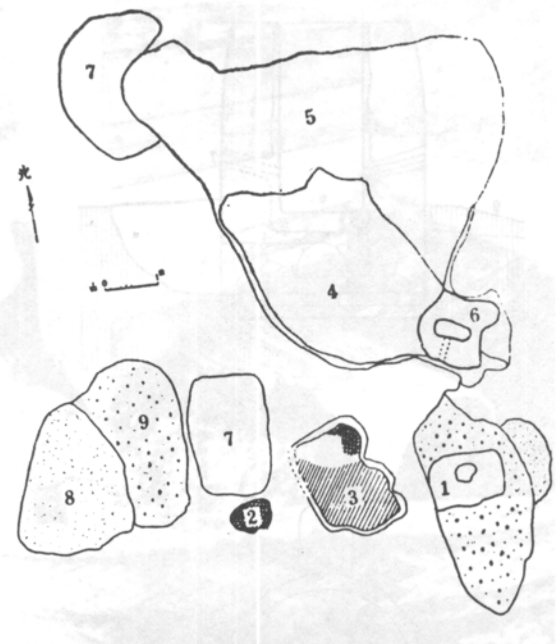


Figure 10. Features in the vicinity of furnace no 6 (20, p 36). The scale shows 1 m, and the arrow points north. 1. Ore-dressing anvil. 2. Clay-preparation pit containing kaolin. 3. Clay-preparation pit containing red clay and kaolin. 4. Working area. 5. Slope up to working area. 6. Furnace. 7. Slag pit. 8. Powdered iron ore (sieve tailings). 9. Crushed iron ore.

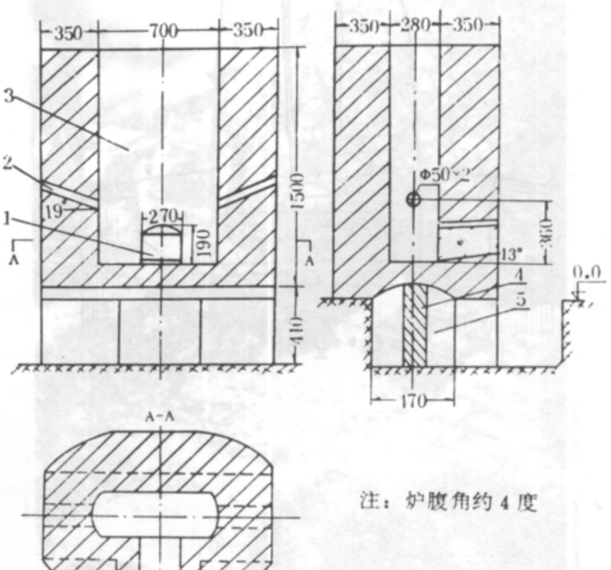


Figure 11. Diagram of experimental furnace no 2, according to (22, p 65). 1. Tapping arch, 270 x 190 mm. 2. Tuyere, ° 50 mm. 3. Shaft, 700 x 280 x 1500 mm. 4. Stone support for hearth. 5. "Wind channel".

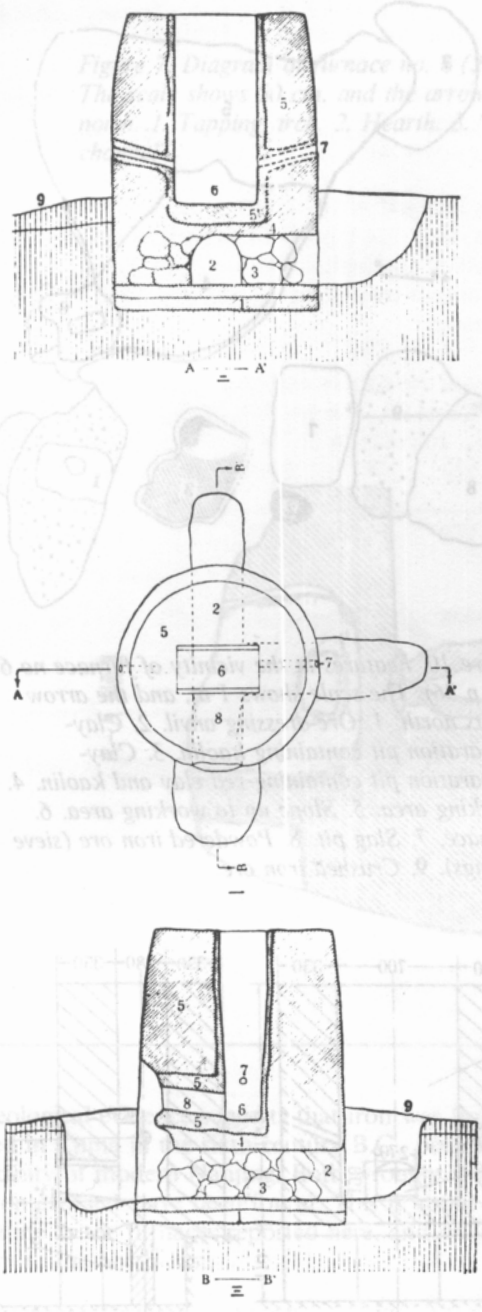


Figure 12. Diagram of experimental furnace no 2, according to (15, p 20). 1. Base. 2. "Wind channel". 3. Stones supporting the hearth. 4. Hearth bottom. 5. Furnace wall. 6. Hearth. 7. Tuyere. 8. Tapping arch. 9 Working area.

Fortunately there is empirical evidence which indicates that a furnace of this size and general construction could be used as an iron blast furnace. I have elsewhere ([36]; see also [35]) described several very small traditional "dwarf" blast furnaces used in various parts of China into modern times. Some of these are as small as 30 cm high. A type of blast furnace used in southern Henan and northern Hubei had a shaft about 2 m high and 45 cm in diameter as its narrowest point. The blast input was only 1.6 m^3/min. The ore used was ironsand with about 65% iron and 5.5% silica. About 1.5 times as much charcoal as irons and was charged. No flux was used, but Ca0 from the furnace lining may have been important in slag formation. Loss of iron to the slag was very small (*Ca* 0.2%). The hearth temperature was normally in the range 1250-1300° C. Production was 700-750 kg pig iron per 24 hours.

The structure of the Tonglüshan furnaces was obviously optimized for copper smelting, and a great deal of experience would have been needed to develop and efficient furnace and operating procedures for iron smelting. Nevertheless the "dwarf" iron blast furnaces are similar enough to the Tonglüshan copper-smelting furnaces to indicate that molten iron could have been produced at some level of efficiency in these with only a small change in operating procedures.

It is conceivable that the "dwarf" iron blast furnaces represent an actual direct development from copper-smelting furnaces of the Tonglüshan type, though I doubt it; the question is irrelevant here, however, and they are mentioned only as an empirical verification of the technical viability of my hypothesis on the origin or iron-smelting in China.

It might be that metallic iron was well-known to the copper-smelters, a sign of incorrect operation of the furnace. Then the discovery of iron-smelting would simply have been the discovery that this undesirable by-product could be useful.

The technical conditions for the discovery of iron thus seem to be clarified, but economic conditions remain to be considered. Why would anyone wish to produce iron at Tonglüshan? There was no shortage of copper ores, production per day would be unlikely to be significantly higher, and charcoal consumption would be considerably higher. The wrought- or cast-iron produced initially would not have been a superior material to bronze. There is in fact no sign that iron was every smelted at Tonglüshan in ancient times. The possibility remains, however, that the same type of furnace was used in other regions where conditions were different: for example at a small copper-ore deposit which at some point was exhausted, leaving only iron ores. In order to continue supplying metal products it would then have been necessary to shift over to iron production.

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Figure 13. Experimental furnace no 2 under construction (11, plate 1.4).

Figure 14. Experimental furnace no 2 under construction (15, plate 5.2).

Figure 15. Charging of experimental furnace no 2 (11, plate 2.3).

Figure 16. Tapping of slag, experimental furnace no 2 (15, plate 5.4).

Table 5 Analyses of raw copper samples (21, p. 166)

location	Cu	Sb	Pb	Zn	Sn	Fe	S
furnace no. 3	93.32	0.0075	0.038	0.014	0.023	3.35	
furnace no. 4	93.99			0.66		3.99	1.33

Table 6 Analyses of artifacts found in the vicinity (13, p. 21)

	Cu	Sn	Fe	Sb	Pb	Al	Zn
bronze axehead	90.27	6.25	1.05	0.18	0.15	0.02	3.01
copper ingot	91.86	0.11	5.44	0.18	0.03	0.01	2.88

Table 7 Analyses of ancient slag samples (22, p. 64)
Compare tables 8-9.

location	form	Cu	FeO	Fe_2O_3	SiO_2	CaO	MgO	S	Al_2O_3
T-36	flake	0.897	53.93	1.54	29.92	3.29	0.86	0.68	7.48
T-45	flake	0.994	53.01	0.90	29.26	2.68	0.86	0.63	6.30
T-45	flake	0.598	50.40	5.32	31.02	2.93	0.71	0.31	6.99
T-37	flake	0.765	48.97	2.29	43.32	2.98	1.12	0.75	10.11
T-33	flake	0.68	47.03	5.75	34.32	4.46	0.97	0.31	8.53
mean		0.787	50.67	3.14	31.77	3.33	0.88	0.54	7.88
inner wall, furnace no. 5		1.06	8.8	2.75	56.98	1.22	0.41	0.20	0.025
beside furnace no. 6	plate	0.995	44.73	5.61	36.74	3.17	0.91	0.39	7.807
inside furnace no. 6	coarse	0.79	36.02	1.84	22.22	1.34	1.33	0.84	4.355
beside furnace no. 6	plate (verdigris precipitant)	1.12	51.81		28.60	3.90	1.62	0.57	6.41
beside furnace no. 6	plate	0.858	50.46	0.53	25.96	1.95	1.51	0.93	6.50

Bibliography

Sections 1-2 below are intended to be complete, while section 3 lists a few interesting recent publications on ancient Chinese mining and metallurgy, and section 4 lists various other publications cited in this article.

Abbreviations

CR: **China reconstrcts.** Beijing China Welfare Institute.

CSA: **Chinese sociology and anthropology.** White Plains. N.Y.: International Arts and Sciences Press.

JHKG: **Jiang Han Kaogu** (Archaeology of the Changjiang — Hanshui region). Wuchang, Hubei: Hubei Provincial Archaeological Society.

JHMS: **Journal of the Historical Metallurgy Society.**

KG: **Kaogu** (Archaeology). Beijing: Science Press.

KGXB: **Kaogu xuebao** (Acta archaeologia Sinica). Beijing: Science Press.

KSW: **Keji shi wenji** (Essays on the history of science and technology). Shanghai: Shanghai Science and Technology Press.

TAIME: **Transactions of the American Institute of Mining Engineers.**

WW: **Wenwu** (Cultural relics). Beijing; Cultural Relics Press.

YJ: **Youse jinshu** (Non-ferrous metals). Beijing: Metallurgical Industry Press.

ZKSY: **Ziran kexue shi yanjiu** (Studies in the history of natural sciences). Beijing: Science Press.

1. The Tonglüshan mine site

In Western languages:

1. **Buck, David D. (tr.), "Reconnaissance of ancient mine and smelter sites in Hupei province"**, *CSA, 1975,* **8**.1:3-18. *Tr. of KG 1974,*4:251-254, 256.

2. **Hsia Nai (=Xia Nai), "The slaves were the makers of history"**, *CR, Nov. 1975,* **24**.11:40-43.

3. **Tonglüshan (Mt. Verdigris Daye) — A pearl among ancient mines.** *Ed. by* **Huangshi Museum, Hubei; Chinese Society of Metals, Publication Committee; and Archaeometallurgy Group, Beijing University of Iron and Steel Technology. Beijing: Cultural Relics Publishing House, 1980.** Chinese and English text. Chinese title: *Tonglüshan – Zhongguo gu kuangye yizhi.* No pagination; in references here the pages have been arbitrarily numbered with the Chinese title page as p. 1.

4. **Vogel, Hans Ulrich, "Bergbauarchäologische Forschungen in der Volksrepublik China: Von Chengde bis Tonglüshan — ein Forschungsbericht", Der Anschnitt: Zeitschrift für Kunst und Kultur im Bergbau** *(Bochum: Vereinigung der Freunde von Kunst und Kultur in Bergbau), 1982,* **34**: 138-153.

5. **Xia Nai and Yin Weizhang, "Digging up an ancient copper mine"**, *CR, March 1982,* **31**, 3:38-40. Abridged and popularized tr. of[11].

6. **Barnard, Noel:** (I understand that Prof. Barnard, of the Australian National University, Canberra, is preparing a study of mining technology at the Tonglüshan site.)

In Chinese:

7. **Hu Yongyan, "Daye Tonglüshan gu kuange yizhu jinnian lai de kaogu fajue ji qi yanjiu"**, *(Recent excavations and studies on the ancient mining and smelting site at Tonglüshan, Daye County, Hubei), JHKG 1981. 1: 77-78. (Not seen; cited KG 1982. 5: 555).*

Table 8 Analyses of ancient slag samples (21, p. 163) Compare tables 7, 9.

location	Cu	FeO	Fe_2O_3	Fe	Fe_3O_4	SiO_2	CaO	MgO	S	Al_2O_3	sample no.
tail slag, furnace no. 4	1.26			49.54	10.00	6.89	0.46	0.43	0.74	5.70	11
tail slag, furnace no. 5	0.625			43.88	8.00	31.92	1.86	0.68	0.58	6.66	10
inside furnace no. 6	0.80	36.02	1.84			22.22	1.34	1.33	0.84	4.36	zha-13
beside furnace no. 6	0.955	44.73	5.61			36.74	3.17	0.91	0.39	7.81	zha-12
ditto	0.858	50.46	0.53			25.96	1.95	1.51	0.93	6.30	zha-15
furnace 3, layer 1	0.58	41.92	7.15			24.11	1.2	0.7	0.76	6.0	12-1
furnace 3, layer 2	0.67	46.70	13.71			25.08	2.0	0.9		3.6	12-2
furnace 3, layer 3	0.20	46.38	14.33			26.90	1.68	2.0	1.02	3.0	
T19-V	0.56			40.15		30.34	3.50	1.17	0.38	6.55	V-17
T36	0.90	53.93	1.54			29.92	3.29	0.86	0.68	7.48	zha-6
T37	0.77	48.97	2.29			34.32	2.98	1.12	0.75	10.11	zha-9
T45	0.60	50.40	5.23			31.02	2.93	0.71	0.31	6.99	zha-8

Table 9 Analyses of ancient slag samples (20, p. 37) Compare tables 7-8

sample no.	location	form	Cu	FeO	Fe_2O_3	SiO_2	CaO	MgO	S	Al_2O_3
12	beside furnace no. 6	plate	0.95	44.73	5.61	36.74	3.17	0.91	0.39	7.81
13	inside furnace no. 6	coarse, excrementoid	0.80	36.02	1.84	22.22	1.34	1.33	0.84	4.355
15	beside furnace no. 6	flake	0.85	50.46	0.53	25.96	1.95	1.51	0.93	6.30
mean of sample nos. 6-10			0.70	50.67	3.14	31.77	3.30	0.88	0.54	7.88

8. **Li Tianyuan, 'Kuangye Keogu zhan xinyan'** *(New work on the archaeology of mining and metallurgy). JHKG 1980. 1*: 98.

9. **Shi Wen, 'Hubei Tonglüshan Chunqiu Zhanguo gu kuangjing yizhi shi nuli chuangzao lishi de guanghui jianzheng'** *(The Spring and Autumn – Warring States mining site at Tonglüshan, Hubei is proof positive that the slaves were the makers of history), WW 1975. 2: 13-18.*

10. **Tonglüshan Excavation Team, 'Hubei Tonglüshan Chunqiu Zhanguo gu kuangjing yizhi fajue jianbao'** *(Brief report on the ancient mining site of the Spring and Autumn and Warring States periods at Tonglüshan, Hubei). WW 1975. 2: 1-12* + plates 3-5.

11. **Xia Nai & Yin Weizhang, 'Hubei Tonglüshan gu tongkuang** *(Ancient copper mines and smelting furnaces at Tonglüshan in Hubei). KGXB 1982. 1: 1-14* + plates 1-2. English summary.

12. **Yang Yongguang, Li Qingyuan & Zhao Shouzhong, 'Tonglüshan gu tongkuang kaicai fangfa yanjiu'** *(Mining methods at the ancient copper mine at Tonglüshan),* parts I-II, *YJ, 1980,* **32**.4: 84-92; 331:82-86, 44. Short English summaries.

13. **Ye Jun, 'Tonglüshan gu kuangjing yihzi chutu tiezhi ji tongzhi gongju de chubu jianding'** *(Preliminary investigation of iron and bronze atifacts from the ancient mining site at Tonglüshan, Hubei). WW 1975. 2: 19-25.*

14. Yin Weizhang, 'Hubei Tonglüshan Dong Zhou tongkuang yizhi fajue' *(Excavation of the Easter Zhou period mining site at Tonglüshan, Hubei). KG 1981. 1: 19-23* + plates 4-5.

2. The Tonglüshan copper-smelting furnaces

15. **Bai Rongjin & Yin Weizhang, 'Hubei Tonglüshan gu tongkuang zaici fajue — Dong Zhou liantong lu de fajue he liantong mosi shiyan'** *(Further excavations at the ancient copper mine at Tonglüshan, Hubei – excavation of Easter Zhou period copper-smelting furnaces and experimental reconstruction of the copper-smelting technology), KG 1982. 1: 18-22* + plate 5.

16. **Jinshu shi wenji (Metallurgical history: proceedings of a conference held in 1980).** *Shanghai: Shanghai Science and Technology Press, forthcoming.* (Not seen; cited in **21**, p. 158, n. 1.) Includes Zhu Shoukang on ancient Chinese copper smelting and Lu Benshan on ancient copper-smelting at Tonglüshan.

Table 10 Phase analysis of slag samples (21, p. 164)

location	copper and copper sulphides	magnetite Fe_3O_4	fayalite Fe_2SiO_4	fine crystals and glass	limonite $2Fe_2O_3.3H_2O$	other
furnace no. 3 (sample 12-2)	Primarily metallic copper in fine grains	10%	65%	15%±		
furnace no. 6		present	present	present	cuprite	(Cu_2O)
T19-5	1%±. Coarser grains primarily chalcocite (Cu_2S); finer grains primarily chalcopyrite ($CuFeS_2$) and bornite ($FeS.2Cu_2S.CuS$).	10%	50% coarse crystals	37%±	2%± Some in veins.	quartz (SiO_2)
T20-6	0.5%±, primarily chalcocite (Cu_2S).	8% comparatively fine-grained	50% coarse crystals	40%±	2%±	

Table 11 Analyses of samples of the ore charged in experimental furnace no. 2 (22, p. 66)

sample no.	Cu	FeO	Fe_2O_3	SiO_2	CaO	MgO	S	Al_2O_3	TiO_2
1	7.08	2.60	72.81	7.12	—	0.16	0.06	0.76	0.12
2	8.07	2.50	71.92	6.51	0.22	0.08	0.03	0.76	0.12
3	11.30	2.43	66.35	6.78	—	0.08	0.03	0.85	0.10
4	8.77	2.44	59.20	11.49	1.93	0.08	0.11	1.14	0.13

Table 12 Analyses of raw copper from experimental furnace no. 2 (22, p. 66)

	Cu	Fe	S	Pb	Sb	Zn	Ni	Sn	Bi
first tap	94.41	3.18	0.117	0.05	0.0036	0.021	0.0078	0.0085	0.0027
second tap	97.25	2.52	0.106	0.074	0.0047	0.035	0.0065	0.014	0.0035

Table 13 Analysis of slag from experimental furnace no. 2 (22, p. 66)
Mean of analyses of each of 14 tappings.

Cu	Fe	SiO_2	CaO	SiO_2+CaO	SiO_2/Fe	(SiO_2+CaO)/Fe
0.837	36.67	32.67	10.00	42.62	0.948	1.194

17. **Institute of Archaeology, Chinese Academy of Social Sciences, 'Hubei Daye Tonglüshan gu liantong lu de reshiguang niandai'** *(Thermoluminescence dating of ancient copper-smelting furnaces at Tonglüshan, Daye County, Hubei), KG 1981. 6: 551, 550.*

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20. **Lu Benshan & Wang Fuguo, 'Hubei Tonglüshan Chunqiu shigi liantong yizhi fajue jianbao'** *(Brief report on the excavation of copper-smelting sites of the Spring and Autumn period at Tonglüshan, Hubei), WW 1981. 8: 30-39.*

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Melting Tin in the West of England: Part 2

Bryan Earl

Editorial Note

This is the second of two papers on the experimental smelting of tin which was carried out with HMS support. The first appeared in the last issue of the Journal, 1985, Vol. 19, No. 2, pp. 153-161.

The 'melting of tin'

Two forms of furnace were used for the investigation. For the first it was assumed that some form of bowl furnace was used before the introduction of the 'Alman' design. It was taken that the fuel was charcoal, the feed some form of cassiterite concentrate, that no flux — other than that introduced from the charcoal ash — was employed, the furnace some form of refractory lined pit and, largely as a convenience, a forced air draft was used; it was well known that an air furnace could readily reach conditions where cassiterite would be reduced to metal, but to work well such a furnace had to be rather large. The second was the blast type.

Bowl furnace

The bowl furnace, shown in Fig. 5, was made up with a mix of equal volumes of powdered potters clay, sand and charcoal dust. This was damped and moulded into shape on top of a layer of sand held in an old fruit can. The charcoal fuel was produced in Spain, and of a hard, compact nature. This arrangement was made as a result of some philosophising over the most likely design the furnace would have followed before the introduction of the 'German' technology. That the central European influence had been considerable can be seen from the almost identical layout of stamps and buddles, along with other mining ideas, which are notably similar for Cornish and German equipment from the sixteenth century — the Cornish layout following the German as described from the sixteenth century — the Cornish layout following the German as described by Agricola almost timber for timber. It is known that German engineers came to the West of England at that time to improve the British methods. Prior to this it seems possible that the bowl type of furnace, which has seen widespread use throughout the world, was the type also used in the West of England.

After some test runs sufficient operating experience was gained for the main work to start. To melt a 'tide' some charcoal, crushed to pea size, was put into a perforated ex-fruit can and ignited by playing a blowlamp flame through the perforations. The glowing charcoal was then tipped into the bowl, which had been well dried, and the tuyere adjusted to aim the blast into the mass. The blower was then turned on and the valve carefully closed until the charcoal was seen to be burning up well, without excessive blasting out of fines. A problem arose from time to time with this charcoal as some pieces were liable to spit with considerable violence but with care this could be contained. The blast was continued and charcoal fed in as required until the bowl was seen to be at red heat in the lower section. The angle of the nozzle was quite critical: too shallow and only the top of the charge burnt well; too steep and the fire was uneven.

When the furnace was well heated, the first trial was made using the Penwith coastal concentrate. This weas fed on after being damped and formed into balls c. 1 cm dia., alternating with charcoal to maintain the charge heaped up over the nozzle. If the black tin was charged dry it was so disseminated that only small prills of metal were formed which proved to be extremely difficult to coalesce; also a large amount of cassiterite dropped through the furnace to form a sandy layer which was soon covered with a fine layer of ash making it resistant to reduction. During the blowing some yellow-white material was seen being deposited on the colder charcoal and the wooden spatula used for charging — this was probably tin oxides blown out from the hot reaction zone. At the end of the melting, the blast was turned off, and the contents of the furnace stirred with a mild steel welding rod for c. half a minute, when a pool of molten metal could be seen under the red hot charcoal. The end of the rod was partly dissolved leaving it pointed and tinned. When the furnace was cold the bulk of the remaining charcoal was scraped off when the tin could be seen as three main buttons, resting on a fine sandy slag. The metal and slag were then separated and the slag vanned to recover a few small prills of tin along with unreduced cassiterite.

Details of the melting:

Total charge of Penwith black tin:	12.31 grammes.
Charcoal added with black tin:	118.00 grammes.
Time of working, after pre-heat:	21 minutes.
Yield of tin metal:	2.95 grammes.
Unreduced cassiterite recovered:	1.96 grammes.
Temperature:	'Bright yellow'.

Taking the concentrate fed to the furnace and the vanned cassiterite recovered from the slags as holding 70% tin metal, this result indicated a 50% loss of tin metal out of the system. Returning the slag concentrate back to the furnace would have increased the yield by 0.69 grammes of metal (assuming 50% loss) showing how important slag treatment was in simple tin smelting. The overall recovery would be 42% of that in the feed.

Such losses would probably be reduced in working on a larger scale, but even so volatilisation can be expected to

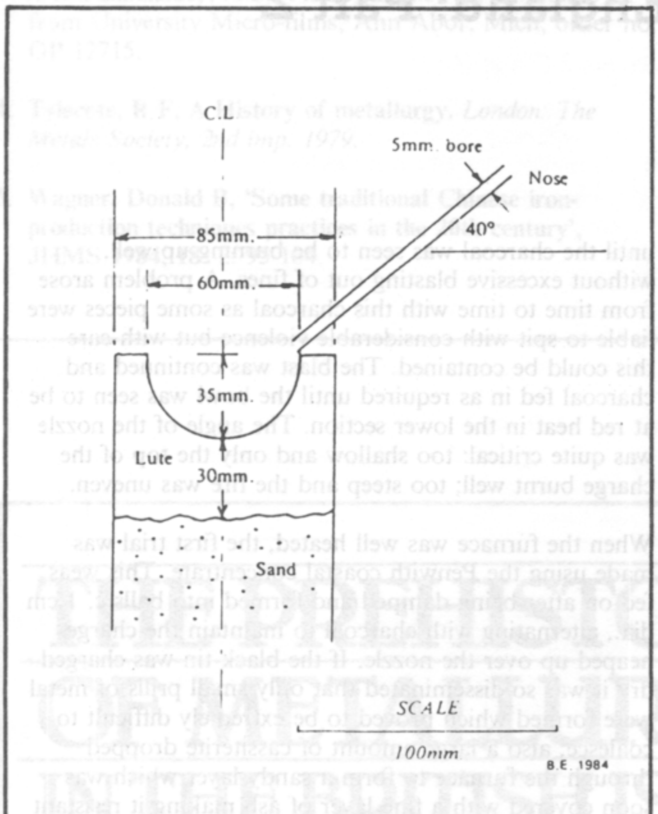


Figure 5. Bowl Furnace - Elevation.

be high in such pit type furnaces with their shallow cover over the reaction zone giving little chance for the oxides to be deposited before being swept out of the furnace. Gowland remarked that these losses were high, in his description of bowl furnace smelting of tin in Japan, which he saw at work in 1883; he noted that fine cassiterite was also blown out.[14]

The sandy nature slag with cassiterite which had been heated to a high temperature, but remained unreduced, was a notable feature of the bowl furnace. Much of this 'high temperature' cassiterite would undoubtedly have been returned by the blowers to the furnace, but some would have escaped in the tails of the concentration operation that would have been needed to free the slag of other material such as glassy slag and gangue. Amongst the general hard baked material in the bowl, small pieces of sintered lining were recovered. An analysis of a sample produced in this trial is given, although the composition will vary as the nature of the refractory mix used for the bowl is changed.

Analysis of bowl sinter (%)

Sn	1.19	CaO	20.55
S	0.126	K_2O	1.85
FeO	4.26	TiO_2	1.85
SiO_2	52.00	MnO	0.64
Al_2O_3	18.26		

A second bowl melting, using the 65.1% Sn South Crofty/CSM concentrate, gave a less satisfactory result. The material was reduced to form small beads of metal but these were contaminated with a mixture of fines that prevented the formation of clean, weighable, prills. With this furnace the concentrate and its nature was obviously critical: readily demonstrating the effect of changes in the feed. The small size of the furnace, dictated by the wish to operate on the small sample of ore from the Penwith coastal traverse, probably enhanced the sensitivity to changes.

Design of blowing furnace

The most detailed descriptions available related to fairly large shaft furnaces lined with clay, blown from one side, and discharging onto the float on the other. This appeared to represent the later practice, say eighteenth century and onwards. A study of the drawings of known Dartmoor furnace remains in Worth[2] and the examination of a good remaining furnace (at Merrivale SX 555754) forced the opinion that the earlier furnaces were not only smaller but of a somewhat different layout. Although some of the Dartmoor furnaces may have been of the 'Pryce' type, most appeared to consist of two side walls and a backwall. The description of an early Cornish furnace indicates a similar design.[20] One description of a nineteenth century German furnace was rather similar, but differed in having the Pryce type 180° relationship of the tuyere and tap hole.[10] Another feature of the German furnace was a plenum chamber behind the tuyere. This was looked for in the West of England remains, but no real confirmation that this arrangement had been used was forthcoming. After pondering these details for some time it looked possible that in the early British type the shaft was fairly shallow and the blast nozzle curved in from the side or front.

Although in discussions over Cornish and Devon mining practice some views had been expressed that Cornish technique was rather different from Devon, this was not always born out by study of actual examples of equipment. One such is the reference to Godolphin mine in Dr. Cotton's account on tin mines in Devonshire in 1643. A later example is the reverberatory furnace used for roasting arsenic ores set up by largely Devon mining interests on the banks of the Tamar which was identical in construction to that used at Wheal Call, near St. Just.[6]

So it was decided that the remains that could be readily examined today on Dartmoor fairly represent earlier West of England practice. Fortified with this decision the design was frozen on a "two side walls, solid back, with side nozzle, luted built up shaft".

Once work started on building this furnace, it was notable that it came together in a most satisfactory manner; it was delightfully simple and surprisingly robust. The nozzle went in with no problems and the situation of the side wall and the thick luting where it was located made it easy to fit and be retained in place. The channel in the float stone formed an ideal profile for the base of the furnace to conform to, and establish

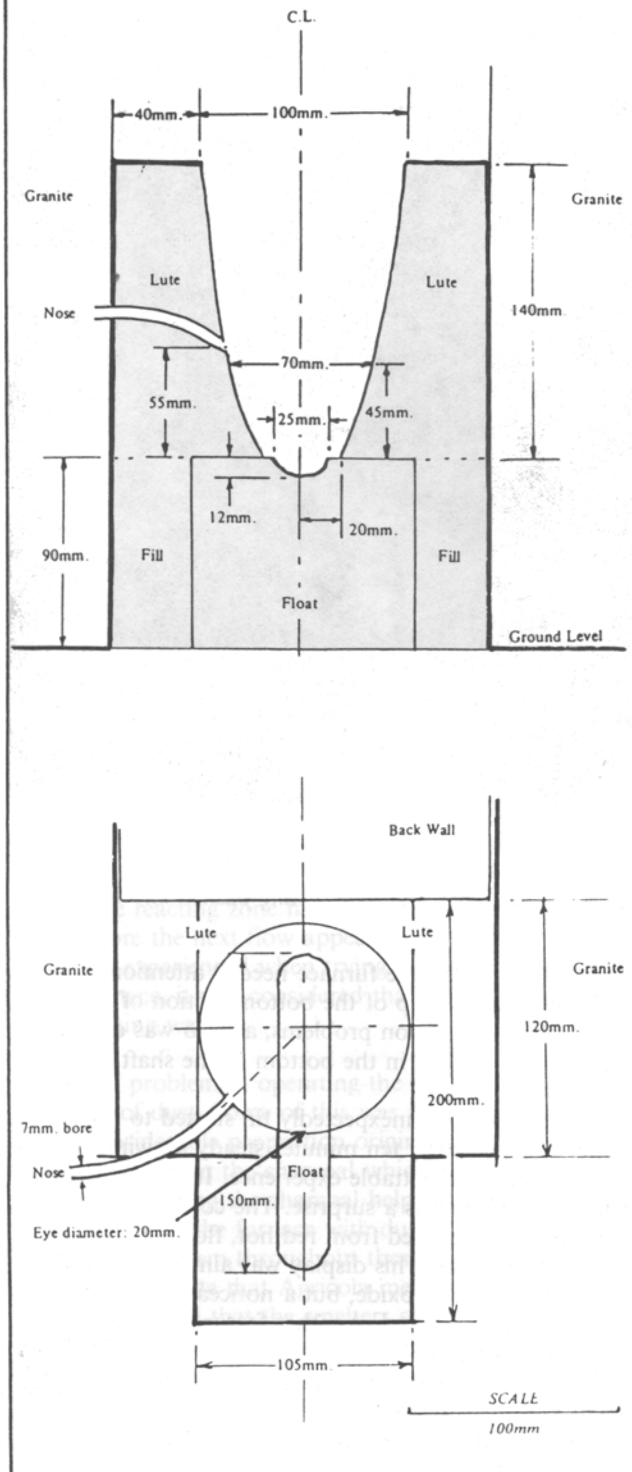


Figure 6. Blowing furnace; elevation and plan.

the 'tyn hole', and provide a strong surface to work onto when drawing out any particularly sticky slag during blowing. An iron plate across the front made it easy to build up the lining and form a suitable shuttering to be removed when repairs to the shaft were needed. The plate oculd be removed and the furnace blown without it, but keeping it in place helped to stop excessive opening of the 'tyn hole' and breakage of the top front portions of the luting. It could have been replaced with either a slab of slate or thin piece of granite, provided a groove was formed at the 'tyn hole' end. (Fig 6).

The sides, back and the float were made of selected granite blocks. The lining consisted of a lute prepared by mixing equal volumes of china clay (ex-St. Just granite), sand from local dunes, and charcoal powder into a thick paste with water. China clay with charcoal was a strong contender as a luting constituent as a lens of just such a mixture was found while examining the tailings from the blowing houses at SX 663724. Small pieces of granite were used as a filler, as the lining was built up in the manner used when building walls. Virtually no cracking occurred on drying out: probably because of the high content of this granite filler.

When the lining was completed the furnace was allowed to dry for a week during a forutnate dry spell; then a small charcoal fire was lit to ensure all the moisture had been removed. When the furnace was in regular use, repairs could be dried out in a day or so.

The work of running-in the furnace and gaining experience was started with some trepidation. From the outset it behaved well, responding positively to all the adjustments tried. Somewhat blackened and singed one began to feel a growing affinity with the long-gone blowers.

The size of the furnace constructed, to enable sufficient work to be done and reach steady state conditions, with reasonable results, was based on experience with the bowl type. The rate at which ore could be reduced, even in the small-size furnace used, was quite astonishing. The limited supply of hard won black tin of a suitable high grade was the controlling factor. Details of the construction and working of the furnace are shown in Figs. 6 to 13.

Trials were then made to find:

— If the design showed signs of working.
— Best entrance height, diameter and angle of nozzle.
— Blast conditions.
— Best size of charcoal.
— Whether charcoal feed should be dry, damp or wet.
— Whether black tin should be added dry or wet.
— Quantity of each portion of feed at each charging.
— Optimum size of hearth 'tyn hole'.
— Effect of closing or opening the 'tyn hole' on the burning pattern.
— Effect of adding a cover of wet grass and added water; used either singly or together, on the burning pattern.

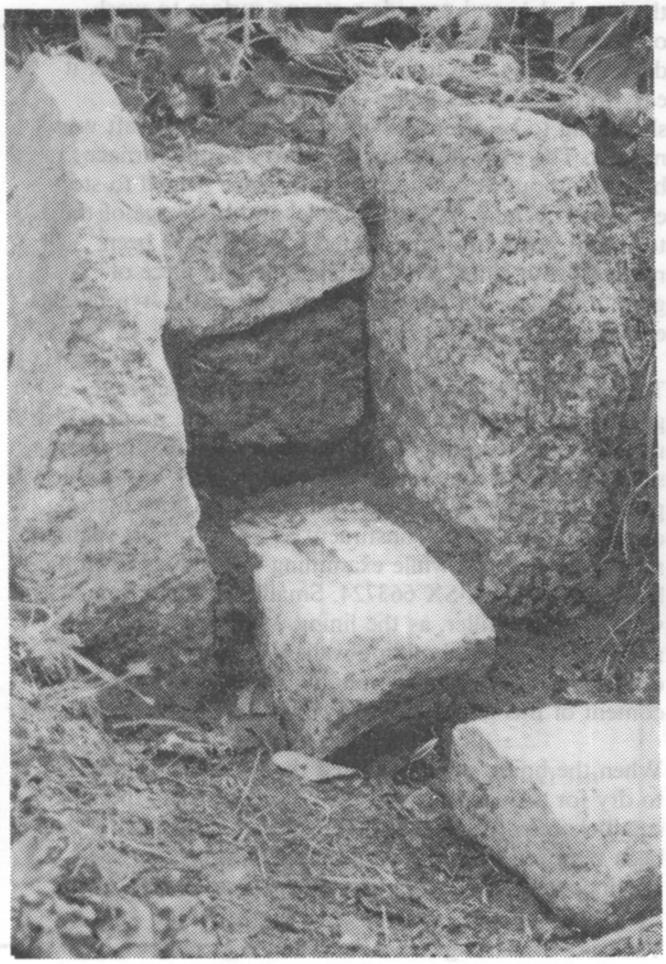


Figure 7. Partly completed furnace with float stone in position.

Figure 8. View looking down the shaft of the blowing furnace. The angle of entry of the blast from the nose is shown by the short length of sapling pushed into the nozzle.

This phase of the work required much qualitative judgement. If the 'hot top' of the charge became *too* hot, spectacular flames of producer gas resulted, often reaching a meter or more high even with this small 'castle'. This was not desirable as it indicated drying of the feed had occurred too soon, encouraging losses of cassiterite as blown dust.

Blowing technique

Several experimental blowings were made to test these points.

When it was thought that satisfactory conditions had been established, 100g of the 65.1% high-grade concentrate was spooned onto the charcoal that had been used to heat the lower part of the shaft to a good red heat. At the same time 60g of charcoal, crushed to pea size, was added proportionately with the black tin. As there was already a full load of charcoal in the furnace, this could not be taken as a true trial of charge ratios. Some wet grass was pressed on top and the whole allowed to blow smoothly. It was found that a great deal could be learnt about the conditions in the furnace by the sound of the blast coming in through the "nose"; as soon as there was any noticeable change it was a sure sign that the furnace needed attention of some sort. Slagging up of the bottom section of the contents was a common problems, as also was excessive accumulation of dust in the bottom of the shaft.

Quite suddenly and unexpectedly tin started to run out of the 'tyn hole' after ten minutes steady blowing, providing an unforgettable experience. Its magnificent iridescent surface was a surprise. The colours settled to a bright blue as it cooled from red hot, flowing along the trough of the float. This display was almost certainly from a thin layer of oxide, but a noticeable quantity of scum was never formed. Another feature was the importance of the open tin hole to the process. With the top of the charge well covered with feed, the differential pressure in the furnace caused a jet of light blue producer gas flame from the hole to play along the groove in the float. This, with hot charcoal also blown out to a small extent from the tin hole, maintained the tin sufficiently hot to keep it molten and protected from further oxidation. If this tin-hole flame disappeared it was another indication that there was a problem in the furnace. The metal nearly always flowed out of the furnace in surges; it seemed that the prills being produced coalesced on the charcoal until large masses were formed which then dropped through the charge.

Figure 9. General view of the blowing furnace with dust-collecting chimney. The slide valve for regulating the blast can be seen in the foreground.

When the reacting zone had been drained, it took some time before the next flow appeared. Bearing in mind the difficulty experienced when trying to melt this feed in a bowl furnace, it was considered that the shaft furnace was working well.

The chief problem in operating the furnace was the build up of dust. Some of this was unreduced cassiterite, but a considerable proportion originated from bulky earthy material in the charcoal which was difficult to remove. Screening the charcoal helped to reduce this, but clogging of the furnace with dust was the most noticeable problem throughout these trials. It is interesting to note that Agricola mentions this as being troublesome and that the smelters screened their charcoal to reduce the fines content. Another difficulty was damage to the furnace lining: the full implications of which did not become apparent until considerably more work had been done. It is likely that the relatively short campaign of twelve hours — a tide — was the normal blow for a West of England 'melting' because the furnace needed to be cleaned out and repaired after reducing the amount of material that could be treated in that time with the size of furnace used.

From the experience gained after several 'meltings' it was obvious that the dust could only be partialy controlled by raking out through the tin hole. Another problem was the build up of 'accretion' on the side of the shaft; the commonest place was over the nozzle where the cold blast caused the freezing of reduced tin and slag to form a hard cake. This was controlled to a certain extent by adjusting the temperature by adding to the 'top', or by the alteration of blast pressure. Also, the accretion could sometimes be chipped off while blowing was in progress. The lining itself became partially impregnated with tin prills and suffered a considerable degree of vitrification. All this material was rich in tin and, in full scale working no doubt, would have been added to slags coming from the furnace for treatment and tin recovery.

Following this work a series of 'tides', usually of two to three hours, was run. It was found that if the furnace smoothly reduced tin for not less than two and a half hours, after pre-heating, before becoming ineffective, the 'melting' gave optimum yield from the charge used. A larger furnace would almost certainly have run for a longer time. The best yield was taken to be the maximum production of both molten tin which had run into the float together with the metallic prills and lumps left in the furnace and recovered at the end of the melting. The yield of tin that flowed onto the float when full scale work started was surprisingly uniform, in spite of wide changes of black tin-to-charcoal feed ratios. However, the tin which could be recovered from the

Figure 10. Blowing furnace at work. The molten tin metal can be seen flowing along the groove in the float stone. Slag and charcoal are being pushed aside with a spoon. The light glow from the "eye" is mainly blue producer gas flame.

Figure 11. The front of experimental furnace has been removed after several smelts. The shape of the shaft formed from the luting can be seen and the position and angle of entry of the nose is shown. Scale = 30 cms.

slags and furnace residues varied considerably. Most of the loss appeared to be in the fines carried off in the blast. The importance attached to dust collecting by the old blowers was well substantiated.

When examining the consumption figures for the charcoal in these tests it must be born in mind that they are based on the feed used for the *first melting* of the black tin. To find the consumption of charcoal to produce a unit weight of tin metal, the charcoal used in the remeltings has to be taken into account.

The main series of 'meltings' was then undertaken and the conditions and results are given in Table 1. The times given are after pre-heating.

The considerable proportion of tin available in the residue from the 'first melting' in the blowing furnace is an indication of the importance of the retreatment operations that were essential for the profitability of the work. As these residues require breaking down to release their values, followed by a concentration process, it is apparent that the blowing houses had well organised stamping and buddling arrangements treating both these residues and probably also working up the feed coming from the tinners. It also points to the probable development of considerable tailings deposits downcountry from the blowing sites, if blowing had taken place for any length of time. These can be expected to hold:

(a) Cassiterite not recovered from initial ore treatment, if this took place at the blowing house.
(b) Cassiterite that had been through the furnace and heated but not reduced, and had escaped concentration.
(c) Gangue from ore.
(d) Fine stampings from 'first melting' slags.
(e) Tin prills: these may have been re-oxidized to mono or dioxides if the site is old.
(f) Charcoal, ex-furnace.
(g) Sandy or glassy slag. Glassy slag likely to hold small prills of tin metal, even if every old.
(h) Furnace lining/lute from stamping to release tin.

Slag treatment may be very ancient, and an examination of its make-up can help in assessing the furnace conditions. Associated or occluded charcoal fragments often occur with such slag, and may be a help in dating work. Furnace lining should also be considered as a basis for thermoluminescence dating; a useful back up as

Table 1 - Blowing Furnace Trials

	1st	2nd	3rd	4th	5th	6th
Tin conc.	100g wet	570g wet	1000g wet	1000g wet	900g wet	1000g wet
Charcoal	60g dry	600g damped	920g dry	2000g dry	900g wet	1000g wet
Metal yield, in float	20g	120g	350g	350g	c. 350g (metal removed for analysis during tide)	395g
Metal yield, in furnace residues & prills ex-slag	25g	50g	155g	15g		48g
Air pressure	—	—	—	—	3¼ in. water gauge	—
Temperature	—	—	—	—	See Fig. 7	See Fig. 8
Time of tide	45min	1hr 45min	2hr 20min	2hrs	1hr 45min	1hr 25min
Slag	—	—	40g 'pitch' like through eye.	55g 'pitch' through eye	—	Pitchlike, 5g, viscous with large tin prills, through eye
Residue — does not include large tin lumps	c. 1g cassiterite on van of residues. 10g slag with c. 5g tin prills	c. 40g tin metal/'cassiterite'	30g slag; 40g 'cassiterite'	Lot of 'dust'	Tin/slag in 'cindery' lump. Temp. low	195g slag, holding 44g tin metal (including 4g cassiterite)
Condition of furnace after	Hard crust around nose	Furnace 'froze' to mass of tin, charcoal & slag	Good tide, some build-up over nose	Collecting chamber used caught dust with c.10% cassiterite	Furnace lining scaled off around nose	'Calcium free' lining. Slag found attached to furnace lining

Notes:
—'Air pressure' was water gauge from plenum pipe immediately before 7mm bore 42cm long 'nose'
— 100g Spanish charcoal on ignition gave 3.25g bulky light grey ash
— In 'Residues': weight reported as 'cassiterite' is weight of tin metal held in cassiterite recovered; tin content taken as 70%
— All weights recorded rounded off to accuracy of equipment
—The tin yield from the 'Residues' is reported in the "Metal yield in furnace (residues) and prills ex-slag".

there is always a lot of organic debris from roots in the 'slimes'.

As the blowing trials progressed the products were scrutinised and compared with those from the old workers. Selected samples from the third and fourth meltings were examined with the scanning electron microscope and the results are shown along with assays made at the same time of old material recovered by vanning from the tailings of the blowing houses at the SX 663724 site on Dartmoor. Examination of this site also yielded samples of charcoal, unreduced cassiterite, slag holding tin prills in the 'glass', gangue minerals — chiefly orthoclase felspar, quartz and tourmaline — and lenses of clay/charcoal powder. No free tin prills were noticed: possibly these had been re-oxidized.

It is apparent from the assay figures that the CaO content reported for the Old Dartmoor slag is far lower than that found in the first set of slags from the early trial blowings (Table 2) (this is also true of the sinter from the bowl furnace melting). As the sand used to make the furnace lining in the work up to this point was known to hold an appreciable proportion of shelly remains from marine organisms it strongly indicated that much of the slag produced in the tin blowing process came from the furnace lining material rather than from the gangue in the ore concentrate. This could explain the feature of the short 'tides' and frequent furnace repair which was notable in the tin blowing process.

Following this, the lining of the experimental furnace was completely broken out, pieces of which showed pronounced vitrification and impregnation of tin prills, and a new lining made in the same way but using the sand tailings from the nearby Leswidden china clay works in the mixture.

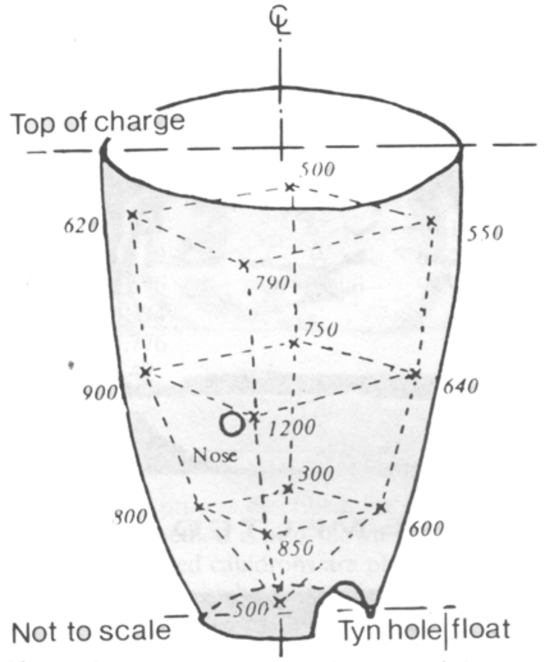
A second alteration was introduced in the rebuilt furnace — the nozzle entrance was moved through 45° to be above the outlet hole. This construction probably represented the layout mentioned in the Harlean manuscript,[13] the nozzle port being the 'eye' and the discharge port the 'tyn hole' of the sixteenth century blowers. This was done to determine if any difference could be revealed in the operation of the shaft or temperature plot.

The 'calcium free' furnace was then blown for a tide as before. Noticeable features were that the charge melted down more rapidly, more tin was recovered direct from the float and there was a considerable reduction in the 'dust' left as residue. However, the slag was more viscous than from the previous meltings and proved difficult to remove through the small 'tyn hole' although it was possible to encourage it to flow out by working the furnace through the tyn hole with sapling lengths. Eventually, at the end of the charging, the furnace had nearly frozen up with congealed pitchy slag.

On breaking open the shaft after the tide it was found that the slag appeared to have originated on (or rather in) the furnace lining below and to one side of the nose. Every indication was that the slag had coalesced at a point of high temperature gradient between the cold air blast coming from the nose to the maximum temperature point in the charge near the nozzle. This was probably 1200°C, and an attempt was made to make a measurement but as this was being done the thermocouple probe was damaged (as had occurred on

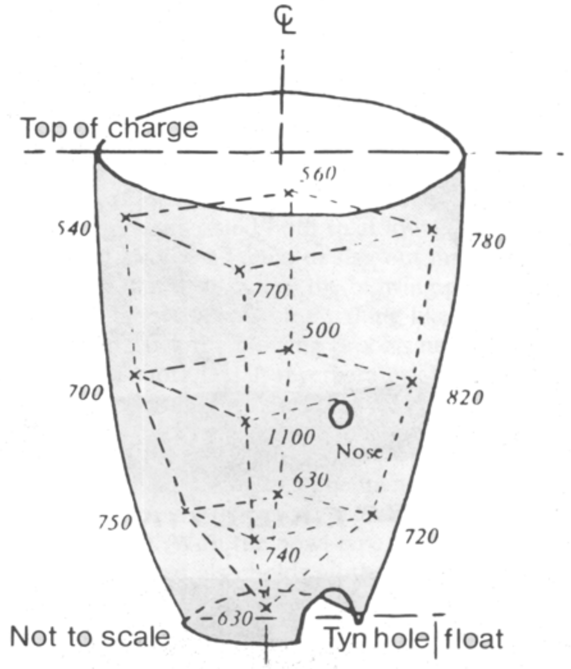
Result of Experimental Smelts with Analysis of Hexworthy Slag for Comparison **Table 2**

%	Products of Fire Assay of South Crofty 40% concs.		Products of Fire Assay SC/CSM concs. "65.1% Sn"			Products of Bowl furnace		SX 663724 Hexworthy	Fourth Experimental Blowing:		Fifth Experimental Blowing:		Sixth Experimental Blowing:
	Hardhead	Metal	Slag	Metal	Hardhead	Sinter	Metal	Slag	Slag	Hardhead	Slag	Metal	Slag
Cu	0.254	0.827	0.44										
SnO_2								7.573			1.768		9.46(SnO)
Sn	71.542	94.013	1.78	102.06	73.39	1.19	99.48		15.078		97.935		
FeO			17.69			4.26		14.740	14.592		13.431		15.28
Fe	29.397	0.191			29.32					40.970			
SiO_2			46.54			52.00		43.828	25.158		21.386		27.76
S		4.938	0.18			0.126							
Al_2O_3			15.74			18.26	15.579	11.022		11.417		10.97	
CaO			4.17			20.55		0.640	15.770		24.915		18.07
K_2O						1.85		1.427			4.006		4.07
K									6.179				
WO_2								1.091	5.311				2.55
W		0.656									3.270	1.103	
MnO_2								0.389	0.855		2.672		
MnO						0.64						1.31	
TiC_2						1.85		5.231	1.390		4.635		0.67
MgO								3.340	1.701		2.128		2.37
P_2O_5								2.240	2.166				1.49
Total	101.958	100.908	86.54	102.06	102.71	100.73	99.48	96.078	99.222	95.507	92.623	99.038	99.02



Blowing furnace temperature in °C. Damaged shaft around nose caused temperature at float to be about 150°C. lower than ideal. Fifth tide.
(Thermocouple probe measurements: D. S. Earl.)

Figure 12. Temperature distribution during the 5th tide.



Blowing furnace temperatures in °C: sixth tide with "central nose".
(Thermocouple probe measurements: D. S. Earl.)

Figure 13. Temperature distribution during the 6th tide.

several previous occasions necessitating re-welding) apparently by being attacked by the molten tin.

The slag was well attached — probably combined at the interface — to the lining and the lining had to be borken to remove the mass.

It was notable that this 6th tide yielded more tin metal in the float than in any previous melting, with less demands for furnace management such as the need to rake out dust. The slag held tin prills which were mostly quite large (c. 3 mm + in diameter) and far easier to separate when the slag was broken than those from the calcium rich 'cinders'. (Fig. 14)

Although rotated through 45° the nozzle in the new "front" position did not seem to have a significant effect on the furnace operation. Although the temperature plot was displaced 45°, the values were virtually identical with those from the earlier design. It did not appear that the change of position had a significant effect on the 'melting'. The different lining material, however, did have a considerable influence. With no change of charge type (both the black tin and charcoal were from the same material as used on the previous blowings) the furnace ran more smoothly, probably because the lining slagged in a different manner. Alas, although the new lining was more refractory the final slag was still rich in calcium upon assay. It seemed the calcium was originating in the charcoal ash: the overall charcoal proportion used per tide being far higher than in full-scale work.

The total yield of metal was similar to a previous tide (No. 3) but the quantity of metal recovered at the first melting was greater. Not only were the prills held in the slag more readily recovered, they were also of a softer nature indicating a lower 'hardhead' or other impurity content.

The significance of the phrase "one heat of the billows be so mighty it will quickly consumeth away the front of the hearth" and lime not being able to withstand the heat in a blowing furnace, is apparent in actual operations. Erosion of the furnace lining is a feature of the blowing process, so that the nature of the lining will influence the slagging properties of a charge. Because of this erosion the conditions in a furnace can change dramatically during a tide. By a suitable selection of blast pressure and charging rate it was possible to set up conditions at the tin hole that gave a good flow of tin. However, after approximately half an hour in the two hour tide used for this investigation, modifications frequently had to be made to keep this happy state of affairs. Accumulations of slag on the side of the shaft could sometimes be broken off and removed using an iron bar, but with the small size of furnace used this operation had to be done carefully. Often it was judged

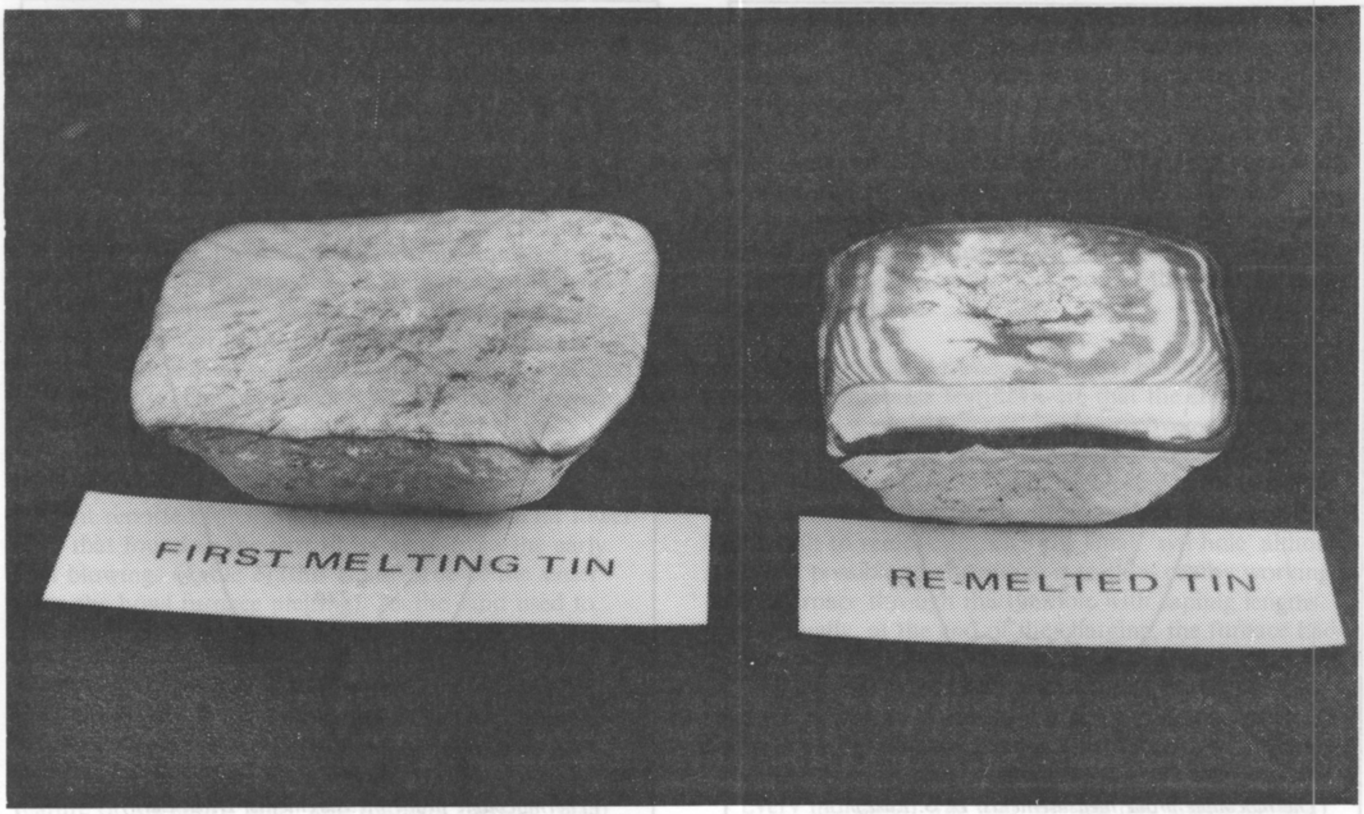


Figure 14. Metallic tin after a first melting and after remelting.

better not to attempt this breaking out. In several runs the furnace geometery changed so that the temperature at the tin hole could not be maintained to give a smooth flow of metal and the tide had to be shortened.

Few blowing house documents remain, but one of considerable interest is the "Charcoal Book" of the St. Austell New Blowing House, which covers the period 1785 to 1806. The woods which were the source of the charcoal are given, along with the quantities obtained from them and the prices and also the amount used in a tide.[21] The tides were of twelve hours but the amount of charcoal consumed for each changed from time to time. Thus in 1785 twenty four packets. Unfortunately no record of the quantity of black tin charged or outputs are given. The figures may reflect changes in furnace size, the result of major repairs altering the overall capacity of the structure, and should be compared with Pryce's "18 to 24 sixty gallon packets of charcoal ..." in twelve hours.[4]

'Remelting'

A trial remelting was made by crucible fire assay in the same way as the assay of the cassiterite concentrates. A quantity of slag from the fourth blowing tide was powdered on the bucking plate, weighed off, mixed with charcoal and then heated in a crucible. No concentration of the slag was made. The assay behaved in an almost identical manner to the 40% metal concentrate black tin. The bright red-hot material in the crucible was very 'sticky' and 'went down' slowly. After heating the material to 1200°C + (by thermocouple) for half an hour the crucible was cooled and broken open. Small blebs of glassy slag holding a large number of hard metallic prills was found. This was examined, revealing the surprising result that the prills were mainly an alloy of iron and tungsten — indeed rich in tungsten.

From this result it is unlikely that the "old men" re-furnaced their slags as a separate operation, but probably stamped the slags to recover tin prills proper which could then be returned to the furnace with the main feed, or melted separately, except for the slag pulled from the furnace that held obvious blebs of unreduced black tin. This type of slag appeared from time to time. The cassiterite rich slag could be recycled into the furnace straight away with the fresh feed. This was done in these trials and only 'straight' slag put on one side. When the furnace was working well, blebs of bright red hot thick treacley slag dripped onto the float at the 'tyn hole'.

With the small size bowl furnace used in these remelting experiments it was found that no true glassy slag was recovered, although a frit of tin metal, cassiterite and fine charcoal was readily formed.

While good tin was obtained in this work by scooping the metal from the float and puring it into the mould to solidify, it was found convenient to add to this 'dirty' metal from the float along with tin prills from slag crushing, and melt these together in a ladle. Slag and hardhead were then removed by allowing the charge to cool somewhat and pouring the liquid tin from the solid impurities. (Fig. 14) This was a 'remelting' and similar

Composition of Products of Crucible Remelt of 4th Tide (%)

Slag from remelt		Metallic prills	
SiO_2	37.998	Sn	9.058
Al_2O_3	14.730	Fe	22.514
CaO	37.227	S	0.115
K_2O	1.719	W	67.277
MnO_2	0.596	Total	98.964
TiO_2	0.374		
MgO	5.776		
Total	98.42		

Table 3

to the purification process described, for example, by Hatchett[8]; such a method is also shown in the Law drawings where heated cauldrons are placed at the side of the 'castle'. It must be borne in mind that retreatment of slags proper, rather than tin metal residues, was practiced in the Far East, as noted by Thibault[11]. Probably both methods were used in the West of England at different times. The slags would have been stamped and buddled to remove tin metal.

Overall Process; conclusions

Throughout these trials it was obvious that some form of scaling effect might be significant. The furnaces were considerably smaller than any found in site remains. It is virtually certain that with larger scale working the efficiencies would be better and the yields proportionately improved. Thus the results show what occurs in the processes but with a degree of uncertainty as to the quantitative outcome. It is reasonable to project from this data to Pryce's figures: the weight of charcoal used being about two and a quarter times the weight of black tin feed (assuming it contained 70% metal), divided between the blowing furnace and the fire for the remelting basin. When 'peate' charcoal was used ("Moor coal, chark't") or a mix of wood charcoal and peat, for the first melting, the consumption would probably be about as for all wood charcoal, but larger quantities of impurities, particularly iron and calcium, would be introduced into the metal and slags.

With smaller furnaces the consumption of charcoal can be expected to increase. Bowl furnace melting would be less efficient than shaft furnace work and the charcoal demands for a given weight of white tin would increase the smaller the bowl. Another effect of decreasing size is that the amount of black tin that can be treated before the furnace requires cleaning out and repairing is also curtailed. This may be the origin of the traditional 'tide' of twelve hours for a melting with the normal size range of furnaces used in the West of England. With large bowl furnaces similar conditions would apply, and one slagging of the lining would be a normal feature.

A factor which has a profound influence on the process is the richness of the black tin. Tin metal recovery drops rapidly as the grade of feed decreases in the blowing process. The gangue minerals — impurities in the concentrate — also have a considerable influence on the process. Thus some are relatively straight: the silica from quartz is relatively easily slagged; on the other hand iron minerals can be detrimental in causing hardhead to be formed which 'ties up' tin metal in a compound that is difficult to treat in the blowing process. It is because the reverberatory process could both treat low grade ores effectively and also be adapted to slag out impurities more precisely that it displaced the blowing process; particularly if the work was on anything like a large scale. To be effective the blowing process needs a feed holding 70% or more metal; reverberatory feeds of considerably under 40% are profitably worked.

The nature of the blowing process did encourage the production of a high purity tin. The high grade feed required usually meant that many detrimental impurities had been removed. With the bowl-type furnace the tin pool that is produced also holds all the hardhead type impurities. Ladling out the tin and pouring it into moulds did give some degree of purification. By evolving the process so that the tin was tapped out of the furnace as it dripped onto the hearth and allowing it to flow into the gutter-like float a form of autopurification was achieved not possible with the bowl type: the pasty hardhead was either drawn out of the float with the slags or left in the body of the furnace as an accretion. It was notable that the quality of the metal left in the shaft of the blowing furnace during these trials was considerably lower than that skimmed from the float. Added to this, scooping the molten tin from the float introduced another purification stage as the hardhead tended to be left on the float. Probably the most significant reason for the reputed high quality of the metal from the blowing process was the need for the very high grade feed. To meet this demand it was apparent that a high degree of skill was required for the concentration work: — appreciation of selective stamping to release the cassiterite in the most effective manner; scrupulous care in the concentration process to obtain the needed grade along with 'burning' when required to clean the ore; and a backup assay technique that *had* to be good to enable the products to be identified. Although nowadays shrugged off as crude and antiquated, it is evident that the vanning assay as practiced by the old blowers was probably giving results *more* accurate than modern X-ray fluorescent equipment: it had to be, or the grade of material demanded by the blowing process to be even reasonably efficient would not have been achieved. If this is doubted, this experimenter invites those interested to go through the actual experience of securing a few kilogrammes of 70% black tin, let alone the 75% material that was frequently produced for the melting.

Metal assay

During the casting and handling of the tin blocks produced by the blowing it was noticed that the tin behaved in a variety of ways. In some cases the cast block had sharp edges, a 'harsh' feel and appearance.

Such tin was hard to chop with a chisel. In others, the solid metal was noticeably clean and shiny, with soft rounded edges and it chopped more readily, fracturing with a fine-structured clean break.

This called to mind the old techniques of assaying the metal: its appearance after being cast into an ingot, the way it cut and the nature of the fracture.

Metal was assayed from the material that had run into the float and cast without any skimming or decanting during tide No. 6, and the same after remelting in a ladle at a temperature only slightly above the melting point, skimming and dragging out dross with a wood splint and then casting. The first run ingot was harsh to the touch and had a sharp edge. That from the remelt was very shiny, smooth, looked particularly clean and cast with noticeably rounded edges. The remelted tin could be chopped more readily than the first run. The importance attached to the appearance of samples prepared by melting and pouring the metal into marble or iron test moulds became obvious on closer examination.

In the later days of blowing it was common practice to force lengths of timber into the tin held in the basin to cause an ebulution that brought up the impurities — 'boiling' the tin.

Alas, the ability of the different samples to make 'grain tin' — columnar shaped granules of metal prized for their high putity — could not be tested. The method used to make them was to cast high grade metal into a block weighing several hundredweight, lift this up over a granite sett floor just after it had solidified and drop it: whereupon it shattered into the characteristic shape on hitting the floor.

It is of interest to note that 'good' tin could be readily stamped when cold with a metal die to produce the smelter's mark.

The well known 'cry' of tin did not seem to be unique to the pure samples; bending thin rods cast from the harsh and soft blocks both emmitted a 'cry'. This property would not reliably distinguish high grade from low grade metal.

Discussion

These trials demonstrate the similarity of tin blowing in the West of England with that of the Far East. Both the size of the furnaces, and their fuel/ore feed consumption — equal weight of charcoal to tin metal produced in the first melting — were virtually the same. The kinship of the operations begs the question: why were they so similar?

After working the blowing process, several 'hunches' came to mind while reviewing blowing sites on Dartmoor. The impression developed that with their small shaft furnaces the blowers arranged the layout so that the capacity of the float's gutter was similar to the amount the associated mould stone would hold. Thus their tide may have been of one float full of impure metal which could be carefully skimmed and ladled free of hardhead before the molten tin was cast into the mould. The blowing set-up looked remarkably standardised for at least four sites. The associated mortar stones for the stamps were also virtually identical: usually for three head of stamps and which, being rectangular, were turned when one face had been worn down to expose a fresh surface for the heads to drop onto and pound the ore. At several furnaces it seemed that the blowing house floor had been constructed at two levels: the higher at about the top of the furnace, the lower at the working level of the float. The higher floor 'room' may have been a chamber for the exhaust gases from the furnace to pass into and allow heavy dust such as tin oxides to settle out and be recovered before the fumes were vented to the atmosphere. This could have been a precursor to the dust collecting chimneys of Carew and the inclined flue and chamber of the later and larger furnaces as dust catching arrangements.

The position of the bellows relative to the furnace remained rather obscure. They may have occupied much of the workfloor at float level: conjested workplaces were the rule rather than the exception in many industrial processes until very recent time. Alternatively, the blast may have been brought by trunking over some distance to the nozzle.

The Dartmoor furnaces and the descriptions by various authors of West of England blowing methods all point to one general design: perhaps the "Agricola type" could fit. After this the reverberatory process took over — a very different skill. Before the "blowing era" it is highly probable that bowl furnaces were used. From the records of tin smelting in the far East it is apparent that bowl methods were of considerable antiquity; and effective too, as they were still in use until the twentieth century. Shaft furnaces seem to have been of recent introduction for tin work — they may have been introduced from the West — although well established for other metals such as iron. If the bowl type was indeed used then the remains of pre-fifteenth century British 'melting' can be expected to be small, and messy. It will tax the archaeologists' skill in a most tantalising manner to unravel the details.

The high value of tin metal brings another problem to the archaeologist. When the sites closed, any remaining metal will have been scavenged. Float stones now appear heaved up at an awkward angle: no doubt 'wreckers' have been seeking tin drips, much as their later brethren crowbared up engine axles to rob the 'brasses' — the brass bearing shells. Therefore it must be expected that all blowing sites will have suffered considerable deformation.

The renowned high purity of the tin metal produced by the blowing process was largely due to the skill applied by the early workers in dressing their ores. Reverberatory techniques enabled what would have been grossly impure feeds for the blower to be smelted by the application of additions to the charge to control slagging.

The examination of assays of slags does not encourage reliance on trace elements to identify ore sources. A blowing house slag *may* be distinguished from a reverberatory slag, as the blowing house slag frequently has a lower iron content. Another feature of the blowing house slag is that if is usually rather full of gas bells, whereas the reverberatory slag is normally more homogeneous. The vanning assay does hold considerable potential as an aid to site analysis. Used carefully it can readily prove the content of tailings which are otherwise hard to find. Gangue minerals, slags, charcoal pieces and unreduced cassiterite are readily exposed and separated.

The presence of charcoal with slag is another indicator of tin blowing. Small — usually only visible under the microscope — prills of tin metal can sometimes be found in tin slags, usually at the slag/bell interface, and thus another pointer to tin reduction. A word of caution is perhaps not out of place here; such prills may be magnetic from a hardhead content, but their brilliant whitness is notable.

Tin metal losses in the blowing process were undoubtedly high. Indeed the figure of up to 15% suggested by some writers[10] is not unreasonable.

The close comparison that can be made between tin blowing in England and that in the Far East invites comparisons of other metallurgical work. Thus the inverted 'flask retort' for mercury separation, as practiced in Spain, can be compare with similar work for isolating volatile metals such as the ancient zinc workings in India.

While this study was to investigate ancient techniques, the blowing process may still have a place in metallurgy. The need to develop third world resources could stimulate its application in regions where small tin deposits occur which could be viable if worked on a small scale with the application of local resources and skill.

Experiencing the trials and problems of the blowers gives one an insight into their working life and 'feel' of the process. Reacting to the demands of their furnaces must have been a constant challenge amidst the dull roar from the nose and flying sparks from the tin hole. One can only admire their skill in preparing and blowing the ore. Their livelihood depended on it.

Indeed, anyone may be able to smelt tin. But there is rather more to it than throwing a few heavy pebbles onto the evening camp fire.

Acknowledgements

I would like to thank R.E. Clough and Miss Effie Photos for the analyses, and the Historical Metallurgy Society for their support for this project. The analytical work was done on the microprobe in the Geology Dept. of University College, London and was assisted by Ian Young. This work could not have been done without the assistance of my son Donald as must have been the case with many of the old men who had help in blowing the tides.

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APPENDIX

The following is a list of the full analyses done as part of this work. Table 2 merely gives the more important results of the experimental smelts.

Index of Samples

BE3	Hard-head from run of November 25, 1983
BE 4	Hexworthy slag, June 1984
BE 5	Smelting slag, April 1984
BE 6	Remelting slag, April 13, 1984
BE 7	Tin ingot, April 13, 1984
BE 8a	Smelting slag, June 9, 1984
BE 9	Hexworthy slag, BE/Hex16.7.84
BE 10	Hexworthy slag, BE/Hex/A/16.7.84
BE 11	Slag, ref 16.9.84
BE 12	Tin metal, ref 3/16.9.84
BE 13	Entral smelter copper slag found at New Sump shaft, Dolcoath mine
BE 14	Slag sample C, December 1984
BE 15	Tin sample B, December 1984
BE 16	Tin sample A, December 1984
BE 17	Tin metal, sample A, ref A/16.9.84
BE 18	Tin metal, sample B, ref B/16.9.84

1. April 13, 1984 4th Run

Slag (BE 5) : Smelting

	Matrix	Metal	Prill
MgO	1.70	Sn	99.18
Al_2O_3	11.02	W	0.84
SiO_2	25.16	Total	100.02
P_2O_5	2.17		
K_2O	6.18		
CaO	15.77		
TiO_2	1.39		
MnO	0.86		
FeO	14.59		
SnO	15.08		
WO_2	5.32		
Total	99.22		

Slag (BE 6) : Remelting

	Matrix	Metal	Prills	
MgO	5.78	Sn	9.06	0.26
Al_2O_3	14.73	W	67.28	72.98
SiO_2	37.99	Fe	22.51	24.01
K_2O	1.72	S	0.12	0.13
CaO	37.23	Total	98.97	97.28
MnO	0.59			
Total	98.41			

November 15 1983 Hard-head (BE 3)

	Matrix		Inclusions	
Sn	95.29	Sn	47.67	71.54
W	0.68	Fe	42.73	29.39
Cu	0.19	Cu	0.42	0.25
Zn	0.13	As	3.85	-
Pb	0.39	S	4.62	-
Total	96.68	Total	99.29	101.18

June 9, 1984 Smelting Slag (BE 8a)

	Matrix		Metal	Prill
MgO	2.73	5.43	Sn	97.94
Al_2O_3	11.42	13.39	W	1.10
SiO_2	21.39	35.99	Total	99.04
K_2O	4.01	64		
CaO	24.92	38.64		
TiO_2	4.64	-		
MnO	2.67	-		
FeO	13.43	4.44		
SnO	2.25	-		
WO_2	3.84	-		
Na_2O	-	0.74		
Total	91.30	99.96		

4th Run

Tin Metal (BE 7)

	Matrix		Inclusions
Sn	98.52	Sn	57.81
W	0.76	Fe	40.97
Total	99.28	W	0.73

Tin Metal (BE 18)

	Matrix		Inclusions
Sn	94.53	Sn	69.97
W	0.93	Fe	30.33
Fe	0.55	Cu	0.57
Total	96.01	Total	100.87

2. September 16, 1984 run

Slag (BE 11) : Smelting

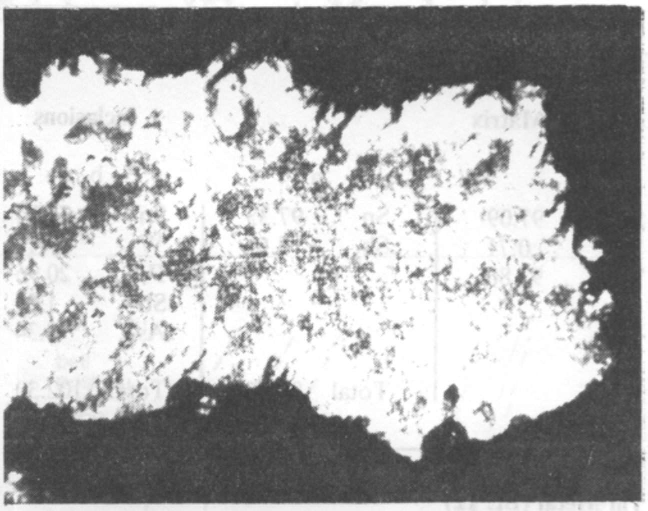
	Matrix		Metal Prill		Other Areas
MgO	2.23	Sn	99.03	K_2O	0.35
Al_2O_3	10.65	W	0.82	CaO	18.85
SiO_2	28.01	Total	99.85	TiO_2	0.21
P_2O_5	1.13			FeO	2.24
K_2O	4.36			WO_2	80.42
CaO	16.64			Total	102.07
TiO_2	1.11				
MnO	0.78				
FeO	15.39				
SnO	12.57				
WO_2	6.49				
Total	99.56				

Hexworthy Slag

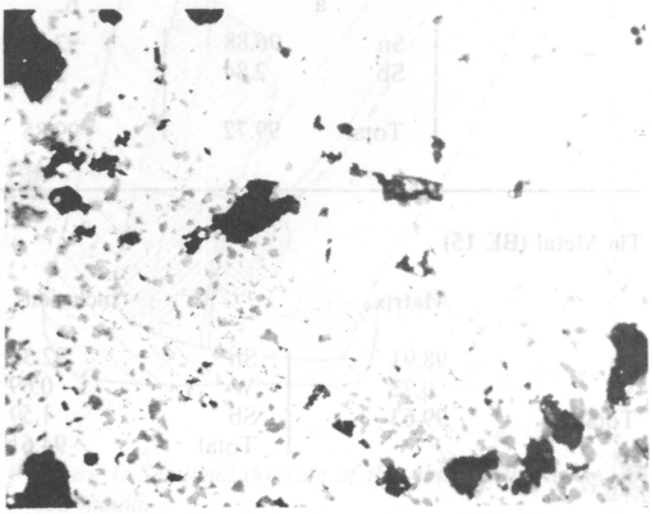
	BE 4	BE 9	BE 10
MgO	3.34	2.59	3.26
Al_2O_3	15.58	16.75	17.02
SiO_2	43.83	45.96	49.12
P_2O_5	2.24	2.49	1.59
K_2O	1.43	1.50	2.14
CaO	0.64	0.64	0.51
TiO_2	5.23	7.33	3.59
MnO	0.39	0.62	-
FeO	14.74	15.39	10.52
SnO	7.57	7.37	10.08
WO_2	1.09		-
Total	96.08	97.56	98.11

Dolcoath Mine Slag (BE 13)

	Matrix		Metal Prill
MgO	0.77	Fe	96.23
Al_2O_3	9.42	W	0.39
SiO_2	50.91	Cu	0.30
K_2O	0.38	Ti	0.37
CaO	28.65	P	0.96
TiO_2	1.11	Total	98.25
MnO	5.44		
FeO	3.31		
SO_2	0.19		
Total	100.19		

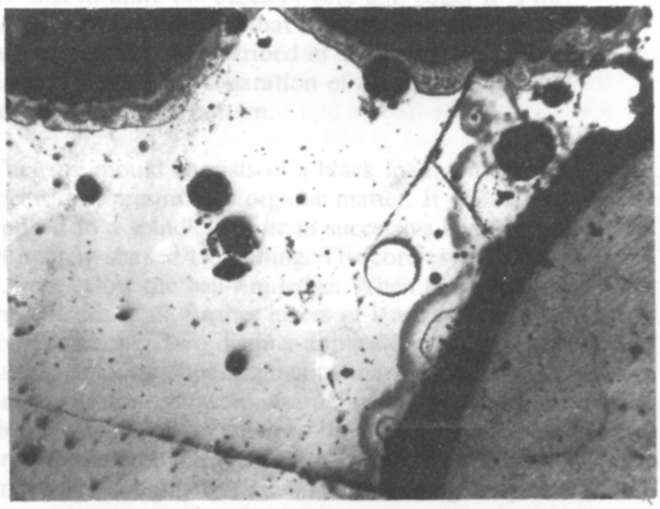


BE3 33x



BE8 125x

BE14 125x



Tin Metal (BE 17)

Matrix		Inclusions a		Inclusions b	
Sn	97.09	Sn	97.33	Sn	71.04
W	0.71	Sb	2.52	W	0.71
Total	97.80			Fe	20.96
				Sb	1.24
				As	8.34
		Total	99.85	Total	102.30

Tin Metal (BE 12)

Inclusions a		Inclusions b
Sn	96.88	97.33
Sb	2.84	2.52
Total	99.72	99.85

Tin Metal (BE 15)

Matrix		Inclusions	
Sn	98.91	Sn	92.33
W	0.72	W	0.69
Total	99.63	Sb	1.59
		Total	94.61

3. December 1984 6th run

Slag (BE 14) : Smelting

	Matrix	Metal	Prill
MgO	2.37	Sn	99.85
Al_2O_3	10.97	W	0.90
SiO_2	27.76	Total	100.75
P_2O_5	1.49		
K_2O	4.07		
CaO	18.07		
TiO_2	0.67		
MnO	1.31		
FeO	15.28		
SnO	9.46		
WO_2	7.44		
Total	99.02		

Tin Metal (BE 16)

Matrix		Inclusions		
Sn	97.69	Sn	92.99	74.13
W	0.49	W	0.48	0.50
Total	98.18	Fe	5.78	25.68
		Total	99.25	100.31

Bell moulds from Kirkstall Abbey, West Yorkshire

H B Duncan and S Wrathmell

In 1954 the Thoresby Society carried out its fifth season of excavations at Kirkstall Abbey, near Leeds, West Yorkshire (SE 259 361). One of the three areas investigated in that year was the monastic kitchen, a rectangular building measuring about 8m by 9.5m. It contained a square, open cooking hearth of several structural phases, positioned towards the centre of the floor. During the later Middle Ages an elongated pit had been cut down against the west side of the hearth.[1] In the bottom of the pit was an annular object of fired clay and 'charcoal', set on a group of hearthstones. This was identified as the upturned rim of a crucible.[2] Fragments of metallic residues lying around it were analysed and found to be alloys of copper.[3]

The crucible, as reconstructed in the drawing by C M Mitchell,[4] had iron suspension lugs, a lid and and inturned rim. It was this last feature in particular which led Dr Tylecote to question its identification: the rim was complete, but it had no pouring lip, and would have presented serious difficulties if the crucible were used for casting[5]. At the same time, analysis showed that the metallic waste was consistent with melting rather than smelting; and the proportion of tin indicated the manufacture of mirrors or bells[6].

The current excavations at Kirkstall Abbey, carried out by the Archaeology Unit of West Yorkshire Metropolitan County Council, are focussed upon the Guest House, a discrete group of remains sited west of the monastic buildings. The Guest House was a self-contained, high-status residence, with its own ancillary buildings. One of these was a late medieval square-plan kitchen with a central cooking hearth. In one corner of the building a pit was found to have been dug through the floor make-up layers. It contained bronze-casting debris and several fragments of a circular baked-clay object reminiscent of the Abbey kitchen 'crucible rim'. Further afield, similar remains have been found at Thurgarton, (Nottinghamshire)[7], and at Cheddar (Somerset)[8] where they have been identified as parts of bell-casting moulds.

In view of these more recent discoveries, Leeds City Museum kindly allowed the Abbey kitchen 'crucible' to be re-examined. The exercise was made difficult by the fact that, in the 1960s, the rim had been incorporated in full and unrestrained reconstruction of a crucible. Nevertheless, it has been possible to reassign the fragments to the rim of a bell-mould — *in situ* when excavated — and to establish some details of manufacture and use which amplify discussions in the Cheddar report.

The relationships of the various mould fragments are illustrated in the sectional drawing (Fig. 1). They belong to the lowest parts of both the core and the cope moulds, and their curvature indicates a bell rim diameter of 34cms. Perhaps the most significant feature of the remains is the skin of clay which extends beneath the moulds to unite the bases of core and cope. It is this feature which indicates that manufacture was by the *cire perdue* method, as described in Theophilus[9]; for it would have prevented the separation of the moulds to allow removal of a clay pattern.

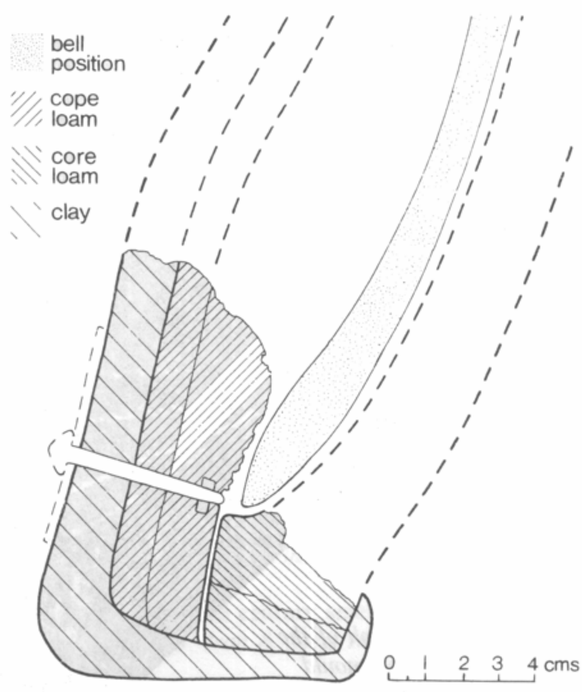


Figure 1: Sectional drawing of the Abbey kitchen bell mould.

The core mould consists of a black loam with fibrous inclusions, presumably organic matter. It will have been applied to a spindle-former in successive layers, and ultimately shaped by turning. The core extended about 3.5 cm below the bell-rim ledge. When the bell had been modelled in wax, further layers of loam were applied to form the cope. Two distinct applications could be seen in the surviving cope fragments, marking a pause for drying. Metal rods were inserted into these layers during their formation: they seem to have been positioned around the mould at 23 cm intervals[10], at bell-rim level, and were probably ties for an iron binding strap. Only two rods can now be observed: one largely as a void,

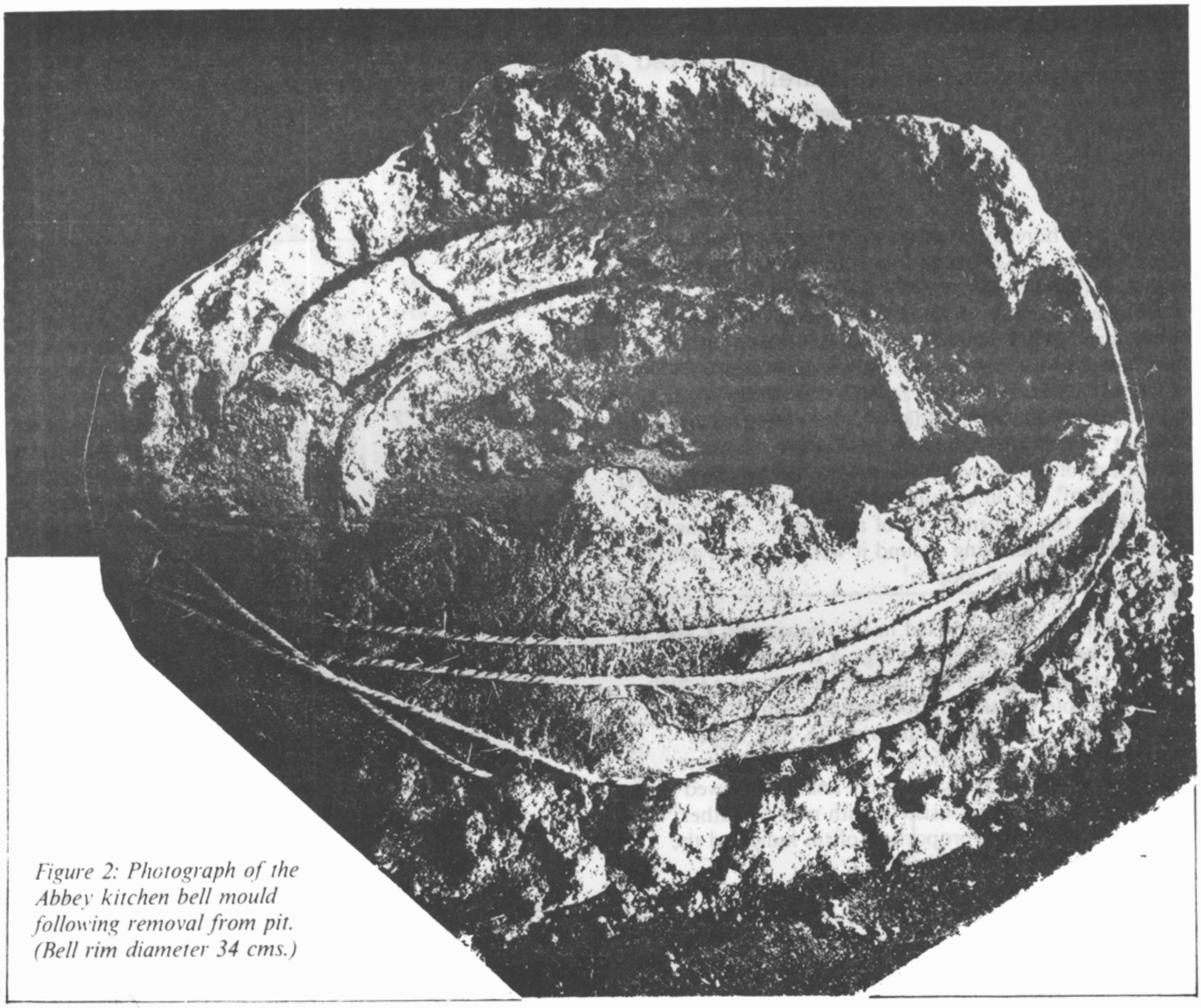


Figure 2: Photograph of the Abbey kitchen bell mould following removal from pit. (Bell rim diameter 34 cms.)

the other more substantial, with some kind of 'washer' embedded in the primary loam to provide further security. The cope loam extended below the wax bell-rim to the same distance as the core, in order to give a better seal for casting. Furthermore, a clay skin which enveloped the cope was continued beneath both parts of the mould and lapped upwards over the inner surface of the core. This lowest part of the skin must have been applied after the former had been removed from the mould. When fired, it had been oxidized to a reddish colour.

The mould was placed on the hearth stones in the pit and fired, to liquify the wax and to remove moisture. The pit was backfilled and casting took place, using metal which had presumably been melted in a furnace set on the cooking hearth. No trace of a furnace was found; but it would not have survived the reinstatement of the kitchen. After casting, the pit was re-excavated to retrieve the bell. The mould was not, however exhumed completely: the cope was broken just above bell-rim level; and during extraction the clay skin ensured that not only the bottom part of the cope, but also the lowest layer of core loam, forming a distinct black fibrous ring, remained intact. The characteristics of the Abbey mould rim (Fig. 2) are also to be found in the examples from Thurgarton and Cheddar[11], and indicate that this method of extraction was employed elsewhere. It is probably to be accounted for by the need to remove the bell rapidly, in order that the core mould could be hacked out before it cooled and expanded[12].

The Abbey kitchen pit contained the remnants of another mould rim — in this case represented only by the lowest parts of the red clay skin[13]. It presumably signifies an earlier casting in the same pit, of a bell of about 30 cms rim diameter. All this activity seems to have taken place over a short period in the 15th century[14], since the cooking hearth was afterwards refurbished, and the backfilled pit was sealed by new flooring.

The Guest House kitchen was used in a similar manner, perhaps even at the same time, for bell casting. The identifiable remains were similar to those of the more fragmentary Abbey kitchen mould: the reddened clay skin from below the mould rim. Only a small portion of the cope loam was still intact. The diameter of the bell rim is estimated to have been about 19 cms. The mould was not *in situ*, and the contents of the casting pit seem to have been badly disturbed, perhaps in the 19th century.

All three Kirkstall moulds can be ascribed with confidence to the 15th century. The comparable remains from Cheddar were dated to the 13th century, and those from Thurgarton to the mid-12th century or later[15]. Strikingly similar to these are illustrations of a mould found at St. Oswald's Priory, Gloucester, which has been dated to the 9th-11th centuries[16]. This last example and the three from Kirkstall are moulds for small bells, with rim diameters ranging from 34cms to 19cms. Those from Cheddar and Thurgarton are almost twice as large. It has been suggested that the *cire perdue* technique was abandoned for large bells after the 11th century, and that its use thereafter was confined to the manufacture of small bells[17]. The Kirkstall evidence certainly demonstrates its continued employment for small bell castings into the later Middle Ages[18].

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7. **Gathercole** *1955, 181-2.*
8. **Rahtz** *1979, 212-6.*
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11. Especially Thurgarton *(Gathercole 1955, 181).*
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17. **Scott** *1968, 192.*
18. We wish to thank Mr Peter Brears and Leeds City Museums for allowing us to dismantle and examine the reconstructed 'crucible', and for permission to publish the photograph which appears here as Fig. 2. Michael Spearman, Stephen Moorhouse and Stuart Blaylock have very generously provided advice on the identification of the mould fragments and on comparable finds.

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XRF analyses of some Anglo-Saxon copper alloy finds from Watchfield, Oxfordshire

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Abstract

Forty X-Ray Fluorescence analyses of Anglo-Saxon period copper alloy objects are presented, from a recent rescue excavation of a cemetery at Watchfield, Oxfordshire. These results are compared with those from Sutton Hoo, together with the few other data available in the literature. It is suggested that these and other Anglo-Saxon copper alloy objects could have been made entirely from scrap brass and pewter, although this cannot be proved from such analyses. In addition, a white metal alloy is identified, containing copper and tin, with a little zinc but no silver, of a type previously found in Continental Merovingian contexts. This together with the more common quaternary metal apparently represents a deliberate attempt to imitate both silver and gold using appropriate copper alloys.

Introduction

A recent rescue excavation carried out by one of us (CS) in conjunction with Richard Chambers of the Oxfordshire Archaeological Unit produced a relatively large number of Anglo-Saxon copper alloy finds. In view of the other authors interest in the history of copper metallurgy, this offered an excellent opportunity to extend the meagre collection of published analyses of Dark Age copper alloys. The excavation itself is in the process of being published, and a preliminary report of one grave containing many of the copper alloy finds is in press (1).

The site came to light in July 1983 during the construction of the Shrivenham by-pass (twenty miles south west of Oxford), when mechanical excavation revealed three inhumation burials. One of these was excavated, but the other two were lost to treasure hunters and completely destroyed. Subsequently more burials came to light, and construction was suspended for five days to allow for rescue excavation. Twenty-three early Anglo-Saxon inhumations were recorded, but the site was very badly damaged by earth-moving machinery, and unstratified grave goods and bones were recovered, bringing the number of identifiable individuals up to around thirty-five. The grave which is the subject of the preliminary report (feature F67) contained a balance set, together with coin weights, in the remains of a leather case, bound with copper alloy bands, one of which is inscribed with runic text. This grave is dated to the second or third quarter of the sixth century (1), and contained many of the copper alloy and white metal finds dicussed in this paper.

The analyses were performed at the Research Laboratory for Archaeology, Oxford University, using Energy Dispersive X-Ray Fluorescence. A large number of copper alloy objects have been studied as part of an investigation of the development of the European copper and brass industries from the Early Mediaeval period through to the Nineteenth century. Some of this data has already been published, or at least summarised (2,3). The details of the analytical method will not be given here — they have been presented in a previous report (2), and will be discussed again in more detail in a forthcoming article (4). A brief outline of the method will therefore suffice in this paper.

Analytical studies of Dark Age copper alloys are, as noted above, rather scarce, and most of the available data have been summarised by Oddy (5), in connexion with his analyses of the Sutton Hoo finds. One of the works referred to in that article is of particular interest, and will be disucssed in more detail below (6). The results presented here add a further forty analyses of early Anglo-Saxon material, and probably increases by fifty percent the available data.

Analytical Method

The method developed in Oxford for the non-invasive analysis of small copper alloy objects (jettons, medals, scientific instruments) was applied to these excavated items. Details of the technique are given elsewhere (2), including estimates of minimum detectable levels (MDL), precision and a comparison with results obtained on the same material by Atomic Absorption Analysis. Briefly, nine elements are measured (iron, nickel, copper, zinc, arsenic, lead, silver, tin and antimony), with MDL's in the range of 0.05% to 0.2% and precisions varying from 1-2% for the major elements up to 10-20% for the trace elements. XRF is of course a surface-sensitive technique, and for quantitative work a clean, flat, homogeneous surface is required. In the non-destructive analysis of museum and archaeological material this ideal is seldom achieved, but careful cleaning of a small area (a few square millimeters) followed by analysis with an X-ray beam of small cross-section (typically 1-2mm) can yield reasonable results, providing that cleaning and analysis are repeated until consistent values are obtained, indicating that surface inhomogeneities due to manufacturing and corrosion have been eliminated.

The above method has been largely applied to objects which exhibit no visible corrosion other than tarnishing, which is easily removed. The Watchfield Anglo-Saxon material was generally heavily mineralised, being covered with green copper corrosion products. This was mechanically removed where possible without extensive damage to the object, but it was not always possible to rigorously clean each sample. The results are best regarded as semi-quantitative, with higher detection levels and poorer precision when compared with previous results from this Laboratory. In addition, many of the objects contain significant quantities of lead which will certainly be inhomogeneously distributed as precipitates throughout the sample. Hughes, Northover and Staniaszek (7) have demonstrated the difficulties associated with lead segregation in large bronze castings. Although all the artefacts analysed here were relatively small, and unlikely to be affected to such an extent by segregation, one must always treat leaded copper alloy analyses with caution unless a metallurgical examination has been carried out.

In some cases the measured concentrations of lead and tin in the samples exceeded the maximum values in the calibration standards (these were 11% for lead and 11.5% for tin). This is clearly undesirable, but at the time that the objects were available for analysis, no other standard copper alloys were accessible. The extremely high tin concentrations found in the white metal alloys are in fact well outside the range of any easily-available copper alloys. These are all reasons for caution in the interpretation of the results, but any errors arising out of calibration or segregation are unlikely to affect the results by more than a few percent (absolute), which would not materially alter the conclusion presented here.

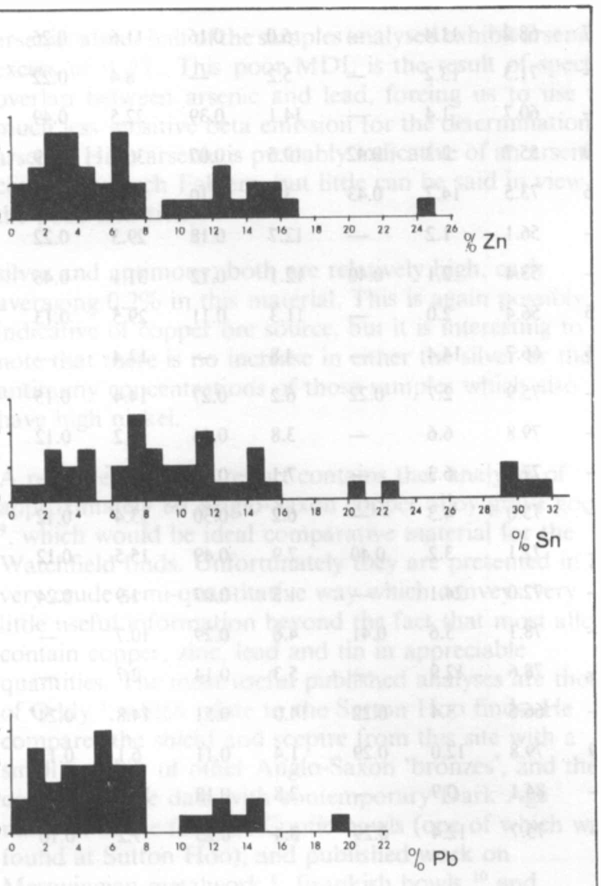

Figure 1. Histograms of the results for Zn, Sn and Pb.

Results

The samples analysed in the course of this work and the analytical results are listed in Table 1. In the following discussion, samples are referred to by their Laboratory number (column 3), although Table 1 does not list these sequentially. With a few exceptions (X3494, X3525 and the "white metals") all the objects are made from an alloy which is best described as "quaternary metal", i.e., a copper-based alloy which contains significant amounts of lead, tin and zinc. From this, it is reasonable to assume that all three alloying metals were deliberately added in some form (but not necessarily as pure metals) rather than entering the alloy as contaminants, as is likely to be the case with iron, nickel, arsenic, silver land antimony. The likely sources of these three metals are disucssed below. The "white metals" are seen to be an alloy of copper with tin and lead, containing no silver. High tin bronzes, called "speculum", are known from the Roman period, and were used for mirrors. These white metals are quite different with a much higher tin content. Similar alloys have been noted in Merovingian metal work (6). The two other exceptions noted above (X3494 and X3525) are essentially brasses, since the lead and tin concentrations are low enough to be accepted as non-deliberate additions.

Discussion

Figure 1 shows histograms (plotted with a one percent interval) of the zinc, lead and tin contents of the Watchfield finds. As noted above, most objects contain significant amounts of all three alloying metals. The following points can be made from Table 1 and Figure 1:

zinc: all objects contain some zinc, although there is a wide range of concentrations (1 to 17%). One sample (X3494) contains 24% with very little lead or tin, and probably represents calamine brass, with no further additions. The other sample with low lead and tin (X3525) has only 16% zinc, but this variability is well within the range of zinc concentrations produced by the calamine process. (See Craddock (8) for a disucssion of the calamine process, and the analytical evidence for its use).

tin: similarly all objects contain some tin, also with a large range of compositions (0.3 to 16%). Two objects have 20% and four are as high as 30%. One object (X3522) is essentially a simple bronze, with low zinc and lead, and one (X3515) is a heavily-leaded bronze, also with low zinc.

lead: most objects contain lead within the range 0.1 to 8%, but a number have between 10 and 15%, and one has 20%. There seems to be no simple relationship between the lead content and the method of manufacture, i.e., the cast objects do not have uniformly higher values than the beaten or sheet objects.

iron: the average iron content of the whole group is 0.3%, omitting the scales set, which has higher range than the rest of the objects (0.4 — 2.2%). It has been suggested that high iron in brass is indicative of manufacture by calamine process, but Craddock (8) has

Table 1. Description of samples and analytical results (%).

Context	SF No.	Lab No.	Description	Fe	Ni	Cu	Zn	As	Pb	Ag	Sn	Sb
F2	9	X3597	Cauldron Fragment	0.18	—	86.4	8.0	—	0.7	0.29	4.5	—
F11	19	X3517	Tweezers	0.35	—	76.7	6.3	—	6.5	0.33	9.5	0.25
F13	21	X3523*	Strap Mount	0.85	0.05	79.7	3.3	0.20	5.6	0.12	10.0	0.18
F14	23	X3521	Disc Brooch	0.17	—	82.6	7.1	0.21	5.3	0.27	4.3	0.11
	30	X3518	Disc Brooch	—	—	83.8	3.4	—	4.5	0.24	4.3	0.11
	33	X3525	Tag/Attachment	0.29	—	82.3	16.9	—	0.1	—	0.3	—
	60	X3515	Ring	0.20	—	71.6	0.8	—	19.7	—	7-4	0.20
F27	35	X3520	Bracelet	0.21	—	80.3	4.6	—	5.7	0.37	8.5	0.21
	36	X3502	Buckle	0.27	—	75.9	2.7	0.22	6.2	0.25	14.4	0.15
	61	X3512	Ear Pick	0.10	0.38	83.2	4.0	0.19	3.0	0.24	8.9	—
	66	X3514	Vessel Binding	0.21	—	66.8	6.4	0.23	5.6	0.46	20.0	0.30
F39	38	X3511	Disc Brooch	0.29	—	90.5	5.0	—	0.3	0.09	3.5	0.34
	39	X3513*	Bucket Binding	0.48	0.20	79.2	9.3	—	2.7	—	2.9	—
F52	74	X3498*	Saucer Brooch	0.06	—	83.7	6.1	—	1.1	0.25	6.2	—
F54	78	X3506	Bow Brooch	0.15	—	77.0	3.5	—	7.0	0.37	11.6	0.24
	79	X3496	Bow Brooch	0.32	—	80.4	1.4	—	5.7	0.19	11.6	0.20
F66	106	X3509	Fragments	0.26	—	85.4	7.3	—	2.5	0.25	4.1	0.12
F67	112		Scales Set:									
	112/A/1*		Balance Arm	1.42	—	66.3	3.6	—	13.5	0.54	14.7	—
	112/A/2*		Pan	2.23	0.07	68.2	11.4	—	6.0	0.16	11.6	0.26
	112/A/3*		Pan	1.68	—	71.3	13.2	—	5.2	—	8.4	0.22
	112/B/1*		Box Binding (with runes)	0.38	—	60.7	1.4	—	14.1	0.39	22.5	0.49
	114	X3503	Buckle — Pin	0.45	0.10	55.7	2.3	0.42	10.5	0.07	30.3	0.19
			Buckle — Inlay	0.17	0.16	73.5	14.7	0.43	3.0	0.10	7.9	—
	115	X3501	Belt Stud	0.21	—	56.1	1.2	—	12.7	0.18	29.3	0.22
	116	X3507	Belt Stud	0.19	—	53.4	2.1	0.40	12.1	0.12	31.1	0.46
	117	X3500	Belt Stud — Stud	0.37	0.05	56.4	2.0	—	11.3	0.11	29.5	0.13
			Belt Stud — Inlay	0.58	0.06	66.7	14.4	—	4.8	—	13.4	—
F71	107	X3508	Spear Shaft Fitting	0.27	—	75.9	2.7	0.22	6.2	0.27	14.4	0.15
	125	X3593*	Bucket Binding/Handle	0.26	—	79.8	6.6	—	3.8	0.16	9.2	0.12
F72	88	X3510*	Sheet	0.69	—	77.7	6.3	—	7.1	0.36	7.6	—
	90	X3516	Stud	0.49	—	75.0	4.3	—	6.2	0.30	13.4	0.12
F75	96	X3499	Saucer Brooch	0.16	—	72.1	3.2	0.40	7.9	0.49	15.5	0.12
	99	X3494	Tweezers	0.34	—	72.0	24.1	—	1.3	0.07	1.9	0.24
	101	X3504	Saucer Brooch	0.27	—	78.1	5.6	0.41	4.6	0.29	10.7	—
F76	92	X3519*	Pin	0.27	—	78.6	12.9	—	5.3	0.14	2.7	—
	94	X3495	Saucer Brooch	0.18	—	66.6	3.4	0.22	14.0	0.51	14.8	0.24
F77	123	X3497	Disc Brooch	0.26	0.09	79.8	12.0	0.29	1.4	0.11	6.1	0.11
F17	25	X3522	Strip	0.26	—	84.1	0.9	—	2.8	0.18	11.3	0.44
48+	8	X3574	Bucket Band	0.63	—	75.7	12.4	0.29	3.4	0.25	7.2	0.10
F1	151	X4011	Strip	(not analysed)								
	136	X4054	Fitting	0.34	—	79.3	10.2	—	7.2	0.07	2.8	0.12
	133	X4016	Sheet	0.17	0.49	77.4	15.6	0.35	1.8	—	4.1	0.16
	139	X4057	Sheet	0.15	0.44	78.0	15.7	0.45	1.4	0.10	3.6	0.19

* = sample difficult to clean — approximate values only
— = less than MDL. These are estimated as: Fe, Ni 0.05%; Zn, As, Sn 0.2%; Ag, Pb, Sb 0.1%.

subsequently doubted this. In our experience early brasses tend to have higher iron than later ones (4), but the measurement of iron in copper alloys by ED-XRF is not simple, particularly when corrosion products may be present, and we cannot therefore say that the observed iron is a result of the manufacturing process.

nickel: most samples contain less than 0.05%. Nickel has proved to be a useful indicator of copper ore source in mediaeval and later copper alloys [2], although it must be said that there are alternative reasons for variation in nickel content other than differing ore sources, such as ore deposit. It is generally agreed, however, that certain Central European copper sources such as the South German Fahlerz ores should exhibit higher nickel concentrations in the finished copper, and also possibly higher arsenic, antimony and silver [8]. Some of the Watchfield finds show high nickel (X3512, X4016 and X4057), which may indicate imported goods, although the use of scrap copper may well give rise to high trace lement concentrations which are divorced from any geographical significance. X4016 and X4057 are fragments from triangular-lugged cauldrons (possibly even from the same vessel), which have been assumed to come from Germany. The observed high nickel concentration is the first independent evidence that this might be so, although X3597 is a piece from a similar vessel, and this is quite different.

arsenic: about half of the samples analysed exhibit arsenic in excess of 0.2%. This poor MDL is the result of spectral overlap between arsenic and lead, forcing us to use the much less sensitive beta emission for the determination of arsenic. High arsenic is probably indicative of an arsenical copper ore such Fahlerz, but little can be said in view of the poor sensitivity.

silver and antimony: both are relatively high, each averaging 0.2% in this material. This is again possibly indicative of copper ore source, but it is interesting to note that there is no increase in either the silver or the antimony concentrations of those samples which also have high nickel.

A recent excavation report contains ther analyses of approximately 80 Anglo-Saxon copper alloy grave goods [9], which would be ideal comparative material for the Watchfield finds. Unfortunately they are presented in a very crude semi-quantitative way which conveys very little useful information beyond the fact that most alloys contain copper, zinc, lead and tin in appreciable quantities. The most useful published analyses are those of Oddy [5], which relate to the Sutton Hoo finds. He compares the shield and sceptre from this site with a small number of other Anglo-Saxon 'bronzes', and then contrasts these data with contemporary Dark Age material in the form of Coptic bowls (one of which was found at Sutton Hoo), and published work on Merovingian metalwork [6], Frankish bowls [10] and Scandinavian Iron Age brooches (late Roman to late Germanic [11]). In addition, he discusses late Celtic copper alloys , examples of which were found at Sutton Hoo in the form of the hanging bowls. The main question concerning Dark Age copper alloys is the extent to which late Roman scrap was re-used, and how mush fresh metal was available to the metal smith. This, of course, is a reflection of the mining and extractive technologies of Dark Age Europe, about which we know very little. Craddock [12] showed that after the first century BC, calamine brass makes up roghly one-third of the Roman copper alloys so far analysed, and Oddy and Craddock [13] remark that in Roman brass tin generally correlates negatively with zinc. They observed that in the Coptic metals, tin is approximately constant (average 2-3%), and that lead correlates negatively with zinc. In his Anglo-Saxon data, Oddy [5] showed that tin and zinc exhibit a correlation coeffient of -0.8. For the Watchfield data presented here, the zinc — tin correlation coefficient is -0.58. In this data, however, zinc and lead are also negatively correlated (-0.59), as are copper and lead (-0.68) and copper and tin (-0.85). Tin and lead correlate positively, with a coefficient of 0.64 (see below). It appears to be difficult at the moment to differentiate between these various metalworking traditions of the basis of such ocrrelations.

Figure 2 shows a triangular plot of the type used by Oddy[5], displaying copper plus lead against tin and zinc. Superimposed on the data from Watchfield are the Sutton Hoo and other Anglo-Saxon results given by Oddy. There is clearly a large degree of overlap in the upper half of the diagram, but Oddy only has one

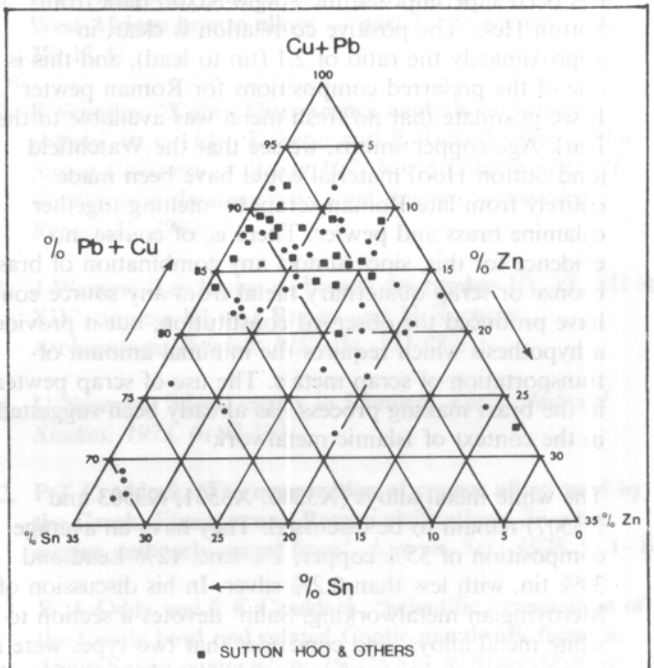

Figure 2. Triangular diagram, Pb+Cu vs Sn vs Zn.

sample falling below 80% copper plus lead, whereas our results show several, including the white metal alloys discussed below. In view of the small number of comparative analyses available, this probably obly reflects the fact that our data is a larger sample and, except for the white metals, suggests that the Watchfield metalwork is from the same tradition as that found at Sutton Hoo.

Oddy[5] argues that the presence of zinc in the Anglo-Saxon, Merovingian and Scandinavian copper alloys indicates the availability of supplies of fresh metal (either imported or indigenously mined). If we assume that metallic zinc was not available in Europe before the end of the mediaeval period[14], then the only method of introducing large quantities of zinc into copper alloys is either directly by the calamine process, or by the addition of scrap brass to the melting pot. The question of Dark Age copper technology therefore reduces to the simple problem of whether they could or could not make brass — if not, they would have had to have used scrap brass (either residual Roman, or imported from the East). The presence of relatively large amounts of zinc in nearly all the Dark Age alloys so far analysed points to the easy availability of brass of some description at this time. It is not possible to resolve this problem analytically as yet — indeed, it may be that it is impossible to solve solely from a chemical viewpoint, and that a detailed metallurgical examination of Dark Age metalworking residues is necessary.

Before leaving this point, one further observation is of interest. It was pointed out above that both tin and lead are strongly negatively correlated with zinc, and, as might be expected, are themselves strongly positively correlated. Figure 3 shows a plot of the tin versus lead concentrations in the Watchfield material, upon which has been superimposed the Anglo-Saxon data from Sutton Hoo. The positive correlation is clear, in approximately the ratio of 2:1 (tin to lead), and this is one of the preferred compositions for Roman pewter[15]. If we postulate that no fresh metal was available to the Dark Age copper smiths, we see that the Watchfield (and Sutton Hoo) material could have been made entirely from late Roman scrap, by melting together calamine brass and pewter. There is, of course, no evidence for this, since almost any combination of brass, bronze or scrap quaternary metal from any source could have produced the observed constitution, but it provides a hypothesis which requires the minimal amount of transportation of scrap metals. The use of scrap pewter in the brass making process has already been suggested in the context of Islamic metalwork[16].

The white metal alloys (X3500, X3501, X3503 and X3507) remain to be discussed. They have an average composition of 55% copper, 2% zinc, 12% Lead and 30% tin, with less than 0.2% silver. In his discussion of Merovingian metalworking, Salin[6] devotes a section to white metal alloys, and concludes that two types were in use — one consisting of copper, lead and tin (as found at Watchfield) and one of copper, silver and tin. The latter seems certain to have been highly debased silver alloy, with, in the Merovingian case, bronze added to the silver as a diluent. Replacing bronze with brass would produce a white metal alloy containing copper, silver and zinc. Some of the Sutton Hoo buckels appear to be in this category (items 145 and 146), which were originally thought to be silver, but qualitative analysis showed them to be copper alloys, containing tin, lead and zinc[17]. Oddy[5] (quoting from Riederer[18]) gives some examples of Ostrogothic brooches containing 15-90% silver debased with brass, originally containing between 9 and 20% zinc. Some Roman silver rings analysed at the Research Laboratory for Archaeology also show a few percent zinc, presumably from the same practice (Mortimer, unpublished data).

The other type of white metal described by Salin, however, appears to be entirely imitation silver, containing very little, if any, of the precious metal. This is the type of alloy used for the Watchfield buckle set (described in detail by Scull[1]). Two of the components (X3500 and X3505) were decorated with appliqué brass (or, more accurately, a quaternary alloy) recessed plates, which in their original state may be presumed to have been yellow, and intended to imitate gold. We therefore have a sophisticated piece of metalwork, with two different copper alloys, both of which were designed to imitate precious metals. Without sectioning the objects, it is, of course, impossible to be sure that they are not bronze cores with a thick tin coating, which might give the same apparent composition when determined by XRF. Microscopic examination of small pits in the surface suggested that this was not the case[19], as does the similarity between these finds and those published by Salin. The closest parallel for the Watchfield buckle set is a buckle loop from Rosmeer in Belgium[20], which is in fact so similar that a common manufacture may be suggested. Unfortunately the Belgian material has not yet been analysed.

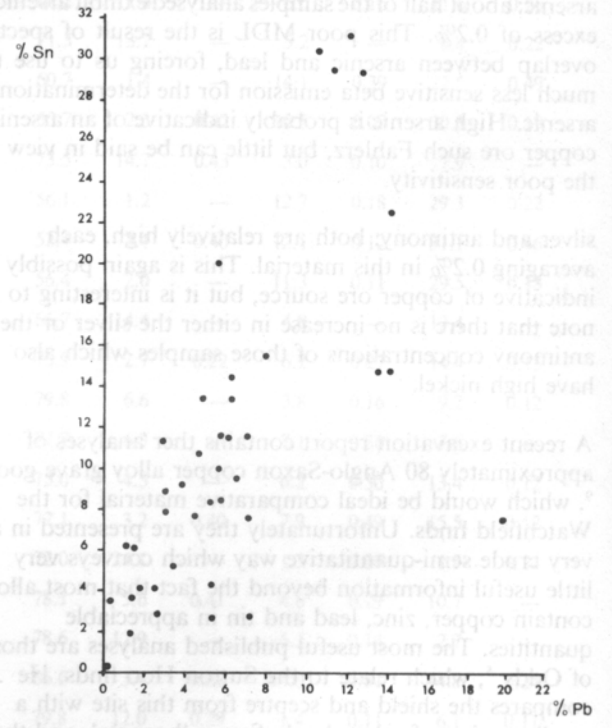

Figure 3. Pb vs Sn.

The Celtic potin coin from grave F67 was part of a small but diverse collection of coins thought to have been used as standard weights for the scales set found in the same grave. Analysis showed that it was made of an alloy very similar to that used for the buckle set, also from the same features (see Table 2). Tylecote[21] gives some analyses of Celtic 'tin money' containing between 22 and 27% tin in a copper alloy, but the similarity between the analyses shown here raises the question of either a Dark Age imitation of the coin or scrap Iron Age coinage being used to produce the buckle set.

One final comment on the subject of Salin's work is of interest. Both Oddy[5] and this paper refer to his (unfortunately incomplete) analyses of Merovingian copper alloys, but one rather remarkable feature has not been discussed. He divides the alloys into four categories — copper, brass ('laiton'), bronze and white metals, and under brass he gives several partial analyses containing over 30% zinc, including two at nearly 38%. Some of these results are supported by metallurgical sections. For reasons discussed at length elsewhere (see, for example, Craddock[12]), 28% is the maximum zinc uptake to be expected by the calamine process, although modifications can increase this to around 33%. These modifications were probably unknown in Europe until c. 1540 A.D.[2] Brass containing zinc in excess of 33% necessitates the use of metallic zinc, not used in Europe for brass making until at least the mid-seventeenth century. The implications of these few analyses are therefore quite enormous if the results can be duplicated.

Conclusions

The copper alloys found at Watchfield consist mainly of a quaternary alloy — copper deliberately alloyed with zinc, lead and tin. Comparison with the data from the Sutton Hoo sceptre and shield shows a similar wide range of alloy compositions. There is an approximate 2:1 ratio between the tin and lead constituents of both the Watchfield and Sutton Hoo objects, and it is suggested that they could have been made simply by mixing together scrap Roman brass and pewter.

The white metal alloy used for the buckle set in one of the Watchfield graves turned out to be a copper alloy containing approximately 30% tin and 10% lead, with very little silver and 2% zinc. The juxtaposition of this alloy with decorated sheets of gold-like quaternary alloy makes this buckle set a piece of sophisticated craftsmanship, consisting of imitation silver decorated with imitation gold. The chemical similarity between the white alloy of this piece and the Iron Age coin found with it deserves further investigation.

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Biographies

Catherine Mortimer graduated in Archaeological Science from the University of Bradford, and in 1984 was appointed Analytical Research Assistant at the Research Laboratory for Archaeology and the History of Art, Oxford University.

Mark Pollard obtained a degree in Physics from the University of York and was awarded a D. Phil. from the same University for research into the chemistry and corrosion of Mediaeval glass windows. He was for six years Analytical Research Officer at the Research Laboratory for Archaeology, Oxford University, and in 1984 was appointed Lecturer in Inorganic Chemistry and Archaeology at University College, Cardiff.

Christopher Scull is a D. Phil. student at the Institute of Archaeology, Oxford University. He graduated in Archaeology and Anthropology from Cambridge University and in 1983 was elected Randall MacIver Student in Archaeology at The Queen's College, Oxford.

Melting points and viscosities of ancient slags: A discussion

Peter Kresten

Abstract

Melting point estimates derived from various phase diagrams have to be regarded as yielding hazardous results. The viscosity coefficient K of Bachmann (1980) does not describe actual viscosities within the working range of furnaces and seems to violate basic concepts of phase diagrams. There is no convenient short-cut to either of the parameters — actual measurements are required.

For the archaeometallurgist, the melting points and viscosities of ancient slags are important parameters, which reflect advances in furnace technology. Both parameters can be measured by instrumental methods. However, methods of estimation of these parameters have been presented which, if accurate enough, could be taken instead of actual measurements.

Melting point estimates

Morton and Wingrove[1] suggested the use of the phase system anorthite — quartz — wüstite for the estimation of melting (liquidus) temperatures. The authors state that ancient slags are mainly composed of wüstite, fayalite and interstitial glass, which corresponds to anorthite in composition. By electron microprobe analyses of a variety of ancient slags it was found that there are no glasses corresponding to anorthite in composition[2]. Accordingly, temperature estimates based upon this phase diagram covering the total chemical variation of slags insufficiently are not reliable. Major variations between estimated and measured melting points are common[2],[3].

For blast-furnace slags, a number of other phase diagrams have been used in order to estimate melting points (e.g. White[4]). However, even in cases where the chemical compositions of all phases — including the glass — are known by quantitative analyses and the most suitable phase diagrams for every case are selected, the estimated melting points deviate from those determined[2]. Although some values arrived at seem quite comparable to the measured values, other values are far off.

The reason for these discrepancies are that there is no system covering the chemical variation of ancient slags. Simplifications have to be made, and any simplifications necessarily involve error factors. Therefore, melting point estimates based upon phase diagrams have to be regarded as being more or less (usually the latter) accurate guesses.

The only suitable method for the estimation of melting temperatures found in the study by Kresten[2] was the calculation of olivine-liquid equilibration temperatures based upon the partitioning of magnesium or iron between co-existing phases. These estimates are thought to reflect liquidus temperatures — the solidus temperatures are most conveniently determined by differential thermal analysis[2].

Estimates of the viscosity

Bachmann[5] discussed the relation between viscosity, temperature and slag composition. He arrived at the conclusion that the viscosities of slags are correlated to the chemical composition by the viscosity coefficient K, which is numerically $(\Sigma RO + R_2O) / (SiO_2 + Al_2O_3)$, all in weight-%. From the coefficient K, the viscosity (n) is either calculated or most conveniently determined from the graph (Bachmann[5], Fig. 7) for any given temperature between 1100 and 1450°C.

There are a number of features of this proposed viscosity to composition correlation which seem quite odd. Firstly, the addition of alkalis is suggested to have the same effect as e.g. the addition of calcium or magnesium. This is certainly not the case: the addition of e.g. albite will reduce both melting points and viscosities in most systems (see Levine 1956). The viscosity coefficient K for pure albite ($NaAlSi_3O_8$) is 0.136. This gives very high viscosities indeed even at temperatures of 1300°C and higher (Bachmann[5] Fig. 7). This is very odd indeed, as the melting point of albite is 1100°C. At 1300°C, according to the K index, albite ought to be a liquid with very high viscosity. Forsterite ($MgSiO_4$), on the other hand, has a K index of 1.342. Accordingly, the viscosity of forsterite at 1300°C is very much lower than that of albite, by a factor of about 1000 (Bachmann[5], Fig. 7). This is again extremely odd, as the melting point of pure forsterite is about 1550°C. Consequently, the viscosity coefficient K shows that the albite liquid at 1300°C has a viscosity one thousand times higher than the solid forsterite. Naturally, the reverse would be much more plausible.

There are no slags composed of pure albite or pure forsterite. It is the principle which is important: addition of albite to the "average slag"[5] will decrease both melting point and viscosity, the addition of forsterite is expected to have the reverse effect. According to the method proposed by Bachmann, the reverse results.

Also, the Bachmann-index takes no account for the presence of other components, such as phosphorus. As this element has an depolymerizing effect on the SiO_4-chains in the melt, it obviously will affect the viscosity.

The correlation between calculated and measured viscosities in the system silica — iron oxide — lime, which is representative for the bulk composition of many ancient slags, is inferior. Williams et al. (1983) published an account on viscosity measurements in this system, including some samples with magnesia as well. The viscosities calculated according to Bachmann deviate from the measured results, both relatively and in absolute numbers.

The viscosity to temperature relationship of three synthetic slag samples is given in Fig. 1. The viscosity coefficients K are calculated to be 2.00 (sample 1), 2.29 (sample 2) and 1.76 (sample 3). According to Bachmann, the viscosities of the samples at all temperatures are thus 3 1 2 (high K-values imply low viscosities). As evident from Fig. 1, the absolute and relative viscosities are dependant upon the temperature, and relative viscosities are:

1200°C	3	1	2
1250°C	3	2	1

The differences in relative viscosities given by the K-index are realized at temperatures above 1400°C (extrapolating the data of Fig 1), but not below this temperature. The low viscosity for sample 1 is explained by the fact that this composition has a much lower liquidus temperature than the others (Fig. 1).

This brings us to another topic. At temperatures close to the liquidus temperature of any given composition, the viscosity of the sample is mainly determined by the liquidus, as evident from Fig. 1. If we consider a binary system between two components forming a binary eutectic then it is evident that, at the temperature of the eutectic, the eutectic composition will have the lowest viscosity as it is the only composition consisting of liquid only. Any addition of either one of the components will result in a higher viscosity.

For a binary system with a congruently melting phase, such as the system wüstite — silica (see Levin[7]), there will be two compositions which within a certain temperature interval will have lower viscosities than any other compositions in the system. In the example chosen (which is indeed relevant when discussing ancient slags), the viscosities of compositions having about 62 and 77 weight-% FeO will have lower viscosities than any other compositions in the system at a temperature of about 1180°C. Any decrease or increase of iron contents to these two particular compositions will raise the viscosities. Again, this is not accounted for by the K-index. The index describes, for temperatures within the whole range of liquidus temperatures possible, the liquidus being a continuous slope from silica plus alumina towards all other components. The utmost consequence of the viscosity coefficient K is thus that it violates all basic concepts of phase diagrams.

This conclusion arrived at is applicable for temperatures within the range of liquidus temperatures possible for ancient slags. At temperatures well above the liquidus temperatures, the viscosities will not be affected so drastically by the position of the liquidus, and will

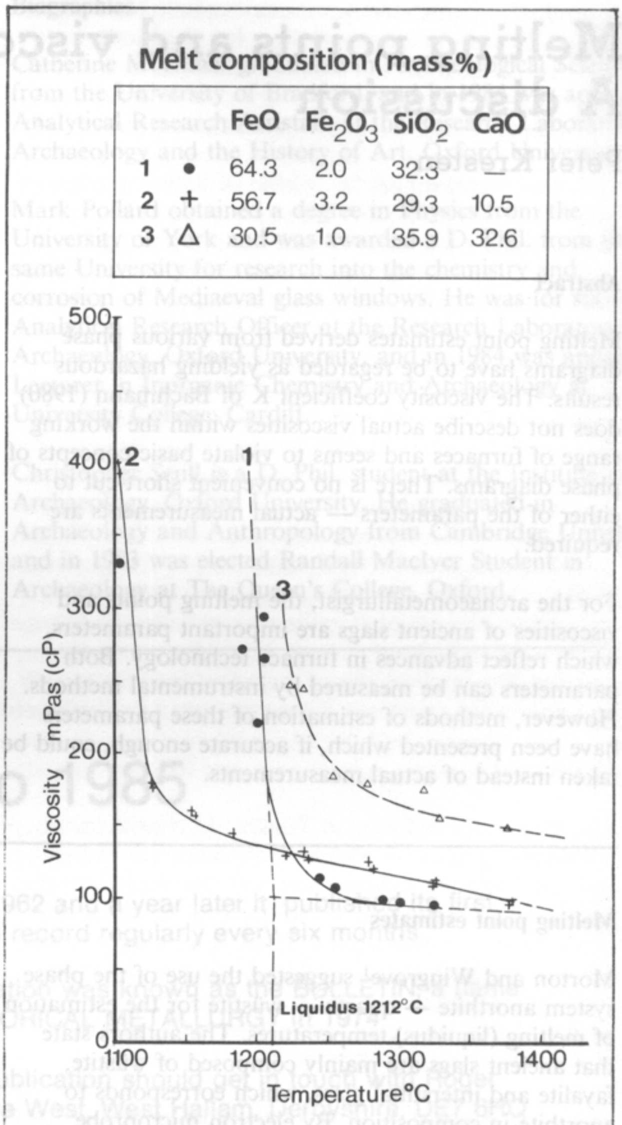

Figure 1. Viscosities versus temperature of lime-iron-silicate melts (from Williams et al. 6).

possibly be much more correlated to factors such as the degree of polymerization of the melt, which again will depend upon the chemical composition.

Conclusions

Both the estimates of melting points using various phase diagrams as well as the estimation of the viscosity from the chemical compositions are gross over-simplifications of natural systems, involving a number of sources of error. With regard to melting point estimates from phase diagrams, the methods have to be rejected even in cases where the composition of all phases are accurately known. The results obtained are hazardous.

The viscosity coefficient K does not describe viscosities within the working range of ancient furnaces in any acceptable way. Any applications of this coefficient have therefore to be strongly rejected.

It seems possible to correlate viscosities and chemical compositions for temperatures well above all possible liquidus temperatures. However, who would be interested in a viscosity number for temperatures well above working temperatures of furnaces and which can not be extrapolated to lower temperatures?

As viscosities and liquidus temperatures are intimately related, there are no possibilities to "estimate" liquidus temperatures from the chemical compositions. Such an attempt would imply programming the accurate position of the liquidus surface of a ten-component-system (or greater) into a computer. As there are no means in experimentally determining such a liquidus, all attempts must fail.

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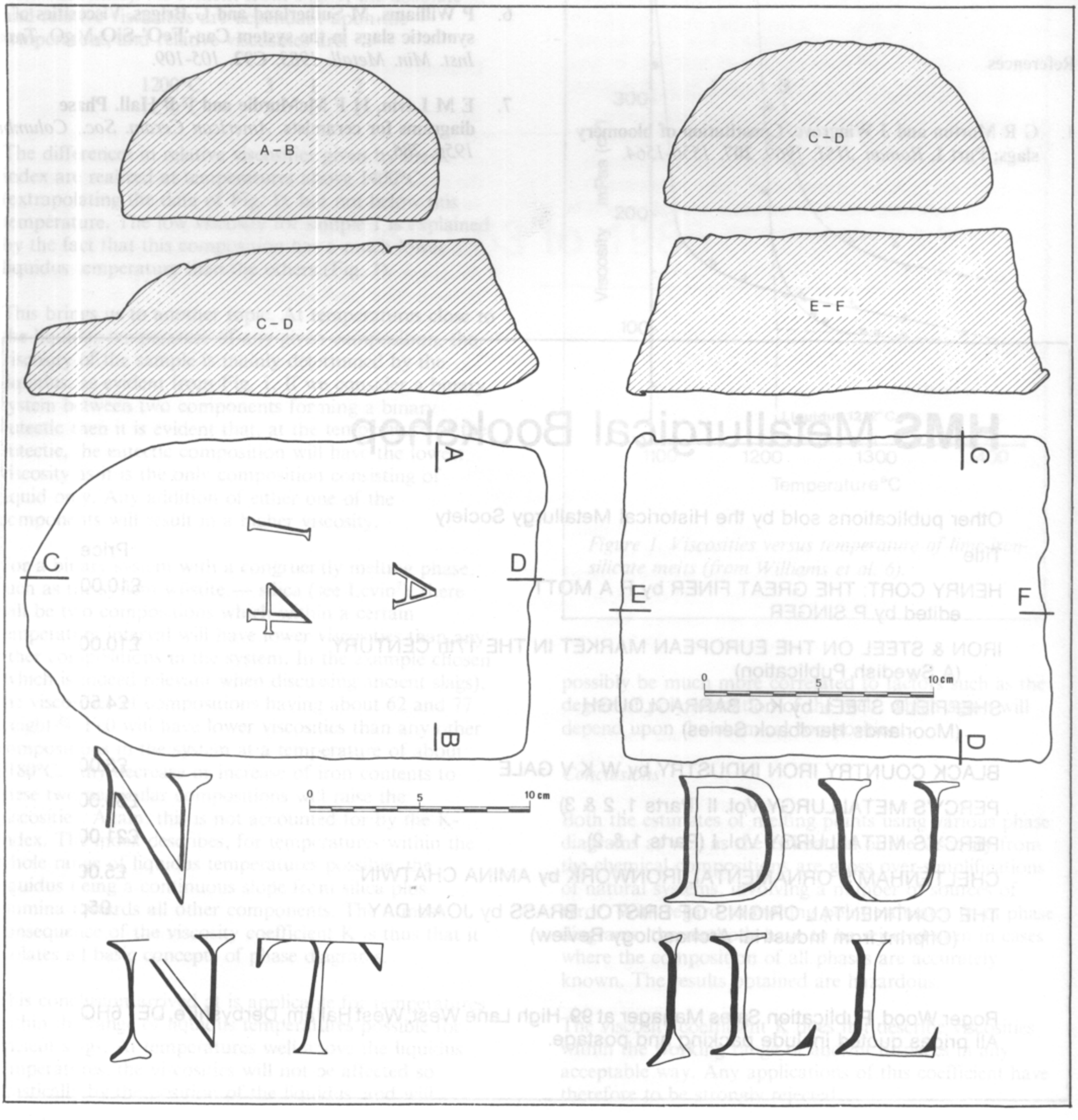
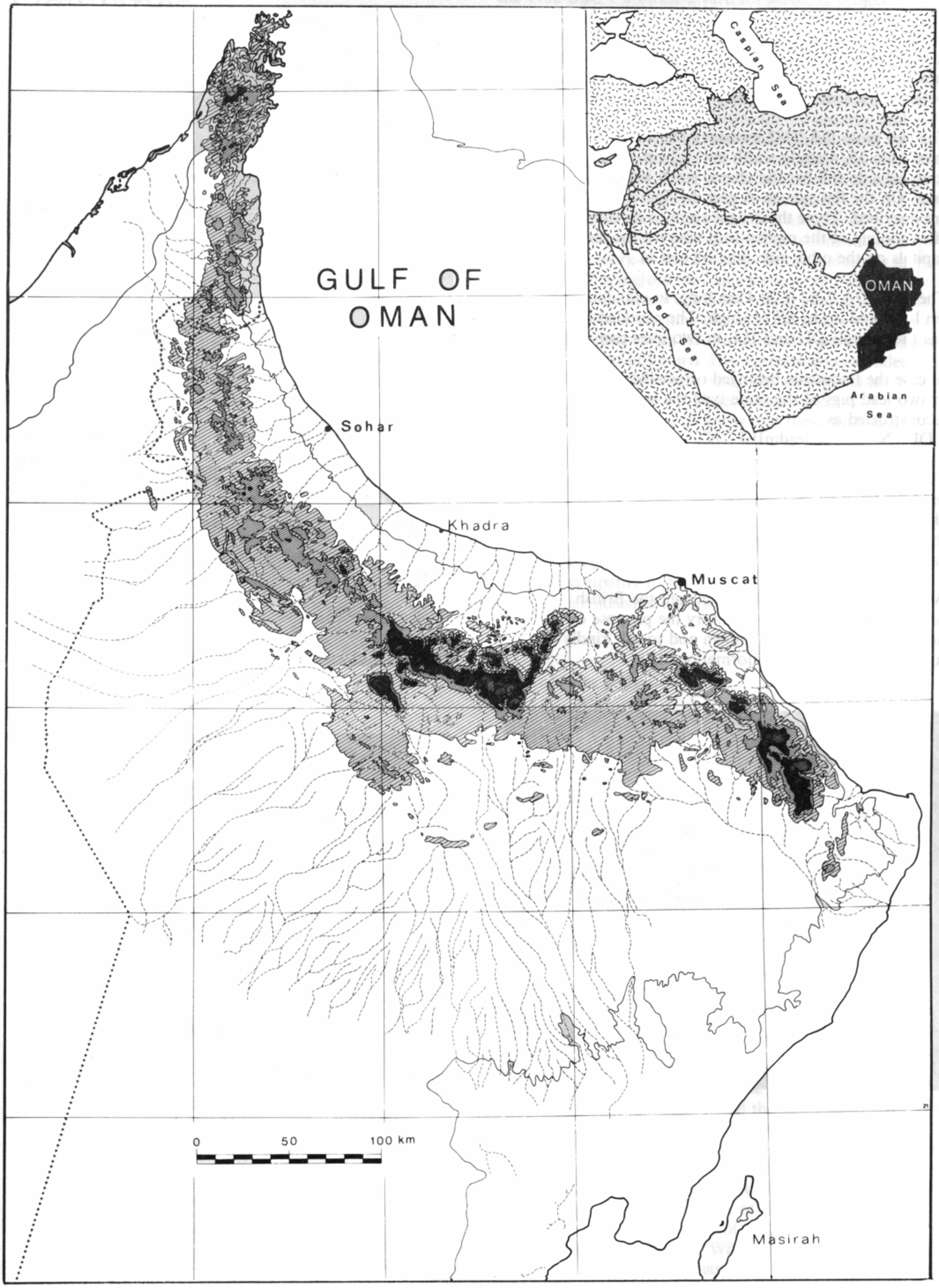
Nineteenth Century British Lead Pigs in Oman

Gerd Weisgerber (Deutsches Bergbau Museum) and
Ali A B al-Shanfari (Department of Antiquities, Muscat)

In Springtime 1985 the Department of Antiquities of the Ministry of National Heritage and Culture in Muscat, Sultanate of Oman, was informed by school boys that they had found two extremely heavy "stones". When Said Ali al-Farsi, Director of Excavations, went to check the situation two fragments of lead pigs were handed over to him. They were found near Khadra (Wilayat Suwayq) a village in the coast plain named Batina 120 km north of the capital Muscat.




GULF OF OMAN
Caspian Sea
Red Sea
OMAN
Arabian Sea
Sohar
Khadra
Muscat
Masirah
0
50
100 km
21

The two pieces belong to one or more lead pigs from which they were cut by chiseling. One piece is the end (Inv No Dep of Antiquities = DA 7782) and the other more or less the middle (Inv No DA 7783) of a lead pig. Both have a semicircular cross section.

The end piece DA 7782 measures 24, 3cm in length, in maximum 15, 4 cm in width and 7.2 cm in height. The rounded side still has the characters N and NT in two lines. On the flat side an A and the figure 14 or 1 and 4 are inscribed. These three signs seem to be stamped in after cooling of the molten lead whereas the large capitals on the other side may be cast in.

The piece DA 7782 is 20,4 cm long, in maximum 15.4 cm large and up to 7.7 cm high. The rounded side still has the capitals DU and ILL in two lines cast in.

In case the fragments belonged originally to one single or two lead pigs of the same type the text could be reconstructed as
...DU...N ...leadmILL...NT

The supposed word LEADMILL proves the British provence of the lead pigs. The gothic type of the characters dates them into the 19th century AD when they were exported to Muscat and Oman probably to be cast into bullets.

As both authors are not familiar with the British lead production during the last century the purpose of this note is to make this find known and to ask kindly for further commentary or information.

Obituaries

Professor Hugh O'Neill

Readers will be sorry to hear that Hugh O'Neill one of our most active friends and supporters died on the 24th February at the age of 86. He was born in Sheffield and graduated in Sheffield University with a B Met and later took his M Met. In 1921 he became a lecturer in the Department at Manchester and in 1929 obtained his D Sc. In 1934 he became Chief Metallurgist to the LMS Railway at Derby until he was appointed to the Chair at University College, Swansea in 1947. He retired in 1965 but continued to live and be active in the area.

His main professional subject was the hardness of metals and he wrote his first book on this subject in 1934; this was followed in 1967 by the Hardness Measurement of Metals and Alloys. He was the author of many papers on this and other metallurgical subjects. He has been President of the Institution of Metallurgists and the Institute of Metals, and the Swansea Metallurgical Society, and was one of the major forces behind the Lower Swansea Valley project in the late 50s. He became a governor of University College in 1981.

RFT

Charles Frederick Tebbutt 1900 - 1985

With the death of Fred Tebbutt last December, British archaeology, and the archaeology of metals in particular, loses a remarkable figure. An amateur archaeologist with long-standing interests in landscapes and their history, he moved on his retirement from his native Huntingdonshire to the Weald of Sussex. He already had a distinguished record of publication and had close links with archaeology in the University of Cambridge, whence many had come to assist his fieldwork and to learn from his capacity for acute observation of change in the Fenland. After the move to Ashdown Forest, there began 20 years of fruitful activity. Fred Tebbutt soon involved himself in the Sussex Archaeological Society and became a significant figure in settlement studies in the Weald. He was the focus for work on many periods, guiding in his patient and unpretentious way the studies of amateurs and professional alike. We shall remember him for his part in the development of the Wealden Iron Research Group, which he, as chairman, steered to its position as the largest and most active amateur group in British archaeo-metallurgy. He was insistent not only on high standards of observation and recording in the field, but on the publication of results: for him, unpublished information was useless, and one of his priorities was that the Bulletin of the Group should be regularly produced and be seen in the national archaeological libraries. That the Group won the 1982 BBC Chronicle award for amateur projects was a source of great satisfaction.

He inspired and encouraged many excavations on ironworking sites in the Weald: for those involved in such work a visit from Fred was always memorable. His enthusiasm was the more effective for its sincerity and restraint, and he always left questions which could not be ignored. his encouragement of excavation was tempered by a belief that the possibilities of field survey must be exhausted before resort to the spade. Nevertheless, he himself carried out a number of significant excavations when crucial questions required answers. His work at the Romano-British bloomery at Cow Park, Pippingford was an excellent contribution; also of great significance was his rescue excavation at the Middle-Saxon smelting site at Millbrook, on Ashdown Forest, which has illuminated a period of the industry hitherto unknown. His interests also extended to experiments in bloomery smelting, and he made available the site used by Roger Adams and his collaborators: it is good to know that these trials will continue.

All members of the Society, and particularly those who attended our Brighton conference in 1979, in which the Wealden Iron Research Group played a major part, will share a sense of loss, tempered by gratitude for the contribution made in our field by Fred Tebbutt. We offer our sympathy to Margaret Tebbutt, who shared so much of her husband's work in the Weald.

David Crossley

Roger Adams adds:—

As many members of the Society will know Fred Tebbutt provided me with every facility over many years for our smelting experiments in that beautiful wooded valley at his house and we owe him a great deal for our present knowledge of the art of early iron and other metal smelting.

When we found the cannon boring bar his rapid action in providing the treatment bath enabled us to prevent further deterioration of this unique object and of course there are many other instances of his kindness and wise counsel being of great benefit to us all.

G Clement Whittick, MBE, MA.

We are sorry to announce the death of Clement Whittick who died in March 1985. He was a collaborator of Dr J A Smythe one of the early archaeometallurgical analysts and the two together concentrated on lead pigs, Whittick dealing with the epigraphy and Smythe with the metallurgy. Most of this took place at the University of Newcastle upon Tyne in the days when it was part of the University of Durham where Whittick was in the Dept of Classics (1923-1964) and Smythe head of the Dept of Metallurgy. After Smythe's death in the 1950s Whittick continued the good work and published many of Smythe's analyses.

This work continued into the 1980s when Whittick reassessed some of the earlier conclusions, and, after a re-examination of some of the pigs made many useful suggestions.

The Society is lucky to have been left Whittick's papers which include Smythe's analytical notebooks, the originals of Whittick's papers and his correspondence, and the "Squeezes" of the inscriptions from the pigs. This valuable archive will be made available to research workers in his field. Application should be made to the Honorary Editor.

11th January 1985 *RFT*

Professor Alexandru Lupu

We regret to announce the death of Alexandru Lupu during sabbatical leave in San Francisco on the 2nd July 1985. Prof. Lupu with be remembered as a collaborator of Professor Aharoni and Rothenberg during their early work in the Israeli Negev when they were finding some of the best preserved early copper smelting furnaces in the World. Lupu's previous experience in the non-ferrous extractive industry in the Muramures region of Romania served him well — indeed it was almost unique in the archaeometallurgical field. His time in Israel was spent at the Technion, Haifa and he was making his first visit to South America and the western United States when he died.

February 1986 *RFT*

News and notes

Indian Copper Mining

In R F Tylecote's report on Early Metallurgy in India published in the Metallurgist and Materials Technologist for July 1984, p 347, mention was made of a copper mine in Central India at Ingaldhal. A piece of timber was removed from the 5th level in the N_{11}-N_{13} zone 30-40 metres below the surface and submitted to the British Museum for a ^{14}C date. The result is now available (BM-2364) and gives a date of 1810 ± 35 bp which when calibrated gives 45-255 AD. K N P Rao comments that the gold mines at Hutti were worked at much the same time and the Megalithic burials are also of the same period. All this agrees with the proved antiquity of mining further north in Rajasthan and shows that Indian mining in general was very active at the turn of the millennium.

Symposium on neutron activation and plasma-arc spectrometry analysis in archaeology.

A one-day meeting with papers on instrumental aspects and applications at the British Museum, Research Laboratory, Great Russell Street, London WC1B 3DG, on Friday 14th November 1986: contact Dr Michael J Hughes (tel no 01-636 1555, ext 282.

Book reviews

The Iron Industry of the Weald

H F Cleere and D W Crossley. *Leicester University Press, 1985, pp 395. Price £47.50.*

This work is a follow-up to Ernest Straker's "Wealdon Iron" published in 1931 and reissued by David & Charles in 1969. Since the date of the original publication, work on the subject had been proceeding consistently if slowly until the formation of the "Wealden Iron Research Group" (WIRG) in 1968 by a meeting convened by the two present authors. This produced a vast increase in the rate of investigation and a high degree of planning and organisation. This book is to a large extent the result of the work of WIRG under the chairmanship of the late C F Tebbutt.

The two principal authors have divided the field somewhat unequally between them. But to start with we have a geological introduction by Bernard Worssam and to complete the work a gazeteer of 80 pages which details the sites investigated by WIRG during their numerous "forays". This is split into three sections, a check-list of bloomeries, Roman bloomeries, and water-powered sites.

The geological introduction deals with iron ore sources in the Weald and discusses the stratigraphy of the various areas. Confusion between iron ore pits and marl pits is dispelled to some extent. Some of the ore mined shows over 70% Fe_2O_3 after roasting but much was of very low grade presumably destined for blast-furnaces.

As an introduction to pre-Roman, Roman and Medieval iron production, Chapter 2 is devoted entirely to the bloomery process. Generally, as far as the Weald is concerned, we see signs of three types of furnace. An Iron Age domed furnace typified by that at Minepit Wood with a maximum diameter of 0.8 m and 1 m high, a slim Roman shaft furnace which is a very common type throughout Roman Britain, and a Saxon non-slag tapping low shaft furnace. Little Farningham looms large in this discussion both for its "bellows pot" and for its 2 kg iron bloom. The latter might better be termed a forged billet and could be compared with recent finds by Prof. Wilkes from Strageath.

The next chapter deals with prehistoric iron smelting and the domed furnaces in particular which lie adjacent to the Roman site of Garden Hill in Ashdown Forest. This section is followed by a general discussion of the Roman industry typified by Cleere's site at Bardown. Here one is rather surprised, considering the enormous amount of slag used in the Roman road system, to find that so little is known about the sites themselves. WIRG work has now recorded 60 sites. Perhaps the use of slag, as in the case of Beauport Park, has destroyed much of the furnace evidence. But in this case little controlled excavation has taken place. Bardown, and several other sites appear to have been operated under the aegis of the Roman Fleet — the *Classic Britannica.*

Bardown however was investigated intensively enough to give us some idea of the quantities of metal produced and the ore and fuel needed. It required about 250 tonnes of ore/year from which it produced 40 tonnes of iron. This would require 25 man-years for ore, iron and timber. As for the latter it is believed that coppicing was introduced during the Roman period. For the 6 major sites the hey-day seems to have been about AD 200-250 when 750 tonnes of iron were produced. If we multiply this by 10 we have an annual production of 7500 tonnes which would go a long way to support Roman needs in Britain.

Clearly the grade of ore worked at this time must have been a lot better than that with 26% SiO_2 used in Medieval times.

We come to the Medieval period after 80 pages and this is clearly the main period of iron working in the Weald. The ^{14}C dates of the shafts and pits give two dates for AD 1200 and one for AD 1600 and one can safely say that these span the main period. The coming of the blast furnace at the end of the 15th century made the use of the more plentiful lower grade ore economic. Before this we have a short introduction on both the un-powered and the water-powered bloomery. The exact site of Tudeley, the best recorded bloomery of this period is still unknown to us due to the poor survival of manorial documents in the Weald. But we do have the 14th century site at Minepit Wood excavated by James Money to make up for it. What a fascinating site it is with an ore-roasting hearth, the remains of the bloomery itself, and other buildings. To add to this we also have Lesley Ketteringham's site at Alstead. This really introduces the heart of the book and, from now on, history makes up for the lack of excavational evidence and allows a better interpretation of the remains visible on the ground.

Forges (bloomeries) were being initiated up to 1477, only 13 years before what was probably the first blast furnace at Buxted, and followed by Newbridge in 1496. The authors are careful with the dating of the blast furnace at Buxted, but clearly cast iron had arrived in the Weald before the end of the 15th century.

Brian Awty would have us believe that this came from across the Channel from the region of Bray. Up to 1550 the industry seems to have been concentrated in the central and northern parts of the Weald. We then have a discussion on the period of the introduction of cast iron up to 1548. While it is generally conjectured that it was introduced for gunmaking, we now know that most guns of this time were of wrought iron. But cast iron was being made as "rough iron" and "rough iron fined", although the meaning of the latter term is in some doubt. But since the price of the second was the same as the first, not much additional work could have been done on the former and we must assume that it was a slightly superior form of cast iron. But much iron was truly fined in the finery — converted to wrought iron — which was of the Walloon type with two hearths.

However, iron gunstones were being cast in large numbers; but it is difficult to agree with the authors' contention that these were being made from "fined iron" i.e. wrought iron melted with the aid of a flux (p 115). It is more likely that "the rough iron fined" was remelted in a cupola or an air furnace (reverberatory). We do not known much about the use of the cupola (if any) at this time, but Réaumur (1722) and Swedenborg (1734) show its use for gunstones.

On the other hand the authors' remarks about the Steel Forge near Pippingford seem acceptable. Steel can be made by the direct bloomery process by using a higher fuel/ore ratio than for wrought iron although it tends to be inconsistant. But phosphoric ores, which abound in the Weald, are not very suitable and one would like to know whether suitable ores were selected or imported. By 1564 Sir Henry Sidney was smelting ore in Glamorgan which has low phosphorus and was using limestone. "Plates" were sent to Sussex to be converted into steel. Sidney was not the only Wealden ironmaster who established his skills in far-off places. Thomas Dyke bought works near Ripon, Yorks in 1590.

By the 1540s cast iron guns were being made in large numbers and by 1574 there were 52 blast furnaces in Sussex. Not all these furnaces were for cast iron ordnance, and by this time some was being converted into wrought iron probably using old bloomery forges.

The "mature" industry after 1548 is better documented and by this time the French immigrants had been well-integrated and dispersed. The records are now more precise and there was an extension to the north-east Weald and elsewhere. Woodlands were coppiced; large timber was saved for other purposes than iron-making and charcoal burners used the tops and lops. Wood and ore were usually taken from the same areas. Ore digging was so controlled as to leave strips of undisturbed ground for trees to grow. Considerable expansion took place by this time, so much so that there were occasional problems with over-production. Would the Crown allow export of guns to enemies of the realm?

More historical material becomes available in time and the authors give us more detail, although it is tantalizing not to be able to calculate the fuel/ore ratio because we do not know the weight of a *load.* It is surprising to find that the decline set in as early as the 16th century, but by AD 1610 there was no doubt. Imports of bar iron increased considerably and the tennant was less able to make a profit. The late 17th century, therefore, showed a decline in the production of bar iron and the founders were turning to other things than ordnance, such as firebacks and graveslabs. Guns were still made off-and-on and there was a great improvement in technical standards. We are now getting some useful information on gun founding and boring. But for the ironfounder and the merchants the condition of the roads and press gangs made transport of the larger items difficult.

The final chapter deals with the archaeology and technique of the industry and the blast furnace period although there is much of a technical nature in the foregoing chapters. This section divorces history from archaeology and deals with the excavations mounted on Wealden sites. Like the rest of the book the somewhat poorly reproduced photos are well supplemented by sketches.

The main structure of the blast furnace seems to have been no more than 28ft (8.54m) high (Gloucester furnace at Lamberhurst) and it is suggested that this might be the limit because of the low crushing strength of charcoal. Yet we know that Russian furnaces were greater than 10m (32.8ft) high at the beginning of the 18th century (Krasartev, Metallurg, 1958 (8), pp 35). In fact, in a vertical tube filled with solid material much of the load is taken by the walls. The limitation of height probably had more to do with the blowing apparatus and water power. Excavation of the casting area confirms the written word that sows of 10-20 cwt rather than lots of small pigs were the normal cast product.

One has no complaint with the contents of this book. It is a good workmanlike treatment of the available archaeological, technical and historical information. One is only a little surprised at the dearth of information on the Roman period. One would like to know how the publishers arrived at such a high price of £47.50, especially when similarly sized books from other publishers are produced at a much lower price. The book merits a wider audience than just a specialised readership. But for the specialist and the research worker in this field it is an essential piece of equipment at any price and it is to be hoped that all academic institutions will buy it.

R F Tylecote

Zinc, S W K Morgan. *Ellis Horwood Series in Industrial Metals. No stated price but on sale for £35 in London bookshops. ISBN 0-85312-762-X. Octavo. pp 245, figs, plates, refs.*

Ken Morgan has just produced a most useful and readable little book on zinc. He is of course known internationally for his work on zinc, particularly for the development of the blast furnace process. However as well an innovator in zinc smelting he has always taken a keen interest in the history of zinc and has produced authoritative papers on William Champion and his role in introducing zinc smelting to the West. During Ken Morgan's visits to India in the 1950s he was able to visit the much earlier remains of zinc smelting at Zawar, and his encouragement and donation of retorts to the British Museum was of great importance in bringing about the current international project on the history of zinc smelting. Thus it is no surprise that the historical chapter which opens the book is so good and gives by far and away the best overview of the early history of zinc production yet to appear in book form.

The bulk of the book is taken up with the extractive processes from roasting to refining. All the processes in use this century are authoritatively described often with a historic perspective, which together with the processes described in the opening chapter means that virtually all the known processes are covered giving a succinct overview of zinc production throughout its history by one who has been responsible for much of the most recent developments himself.

Whole chapters are donated to the electrolytic processes which currently account for the bulk of world production, and to the blast furnace process. This latter emphasis is also appropriate, not just because of the author's special knowledge and involvement but it does seem that the ability of the blast furnace process to handle relatively low grade ores and residues will bring it into ever increasing prominence as high grade zinc deposits become exhausted.

The other chapters on the physical metallurgy, alloys and uses of zinc are much less detailed by comparison. There are separate chapters on corrosion protection and on the production and uses of zinc based chemicals.

For all the book's historic perspective written by a now retired senior figure the book is completely up to date and draws on the latest data and published sources for its material. It is in no way just an up-date of Morgan's earlier works. It provides an excellent survey of the methods used and in use to produce zinc and is to be recommended.

The price is high considering the size and scope the book and I fear will deter all but a few institutional librarys who need to buy it. This is a great pity and missed opportunity as a soft cover edition which might sell at a third or even a quarter of the price would form a very useful text for a student or an HMS member who might wish to own as well as consult.

Paul Craddock

Abstracts

GENERAL

H G Backmann and H Renner: Nineteenth century platinum coins, an early use of powder metallurgy. *Platinum Metals Review, 1984,* **3,** *126-31.* Reviews the history of attempted introductions of platinum coinage and the role that these attempts played in the development of powder metallurgy for refractory metals. The early history of the isolation of platinum from its metallic impurities is discussed.

AATA

M Burteaux: History of the blast furnace through the development of refractories. Future Prospects, *Revue de Mét. (C I T), May 1985,* **82,** *(5), 357-72.* The greater part of the article is concerned with developments in the 20th century.

APG

P T Craddock: A History of the distillation of metals. *Bulletin of the Metals Museum of the Japan Institute of Metals, 1985,* **10,** *3-25.*

Traces the development of metal distillation from arsenic through mercury and zinc. The technology and interrelationship between the various methods of distillation is discussed with many contemporary descriptions from India, Europe and China.

PTC

P T Craddock and M J Hughes (eds): Furnaces and Smelting in Antiquity. *British Museum Publications, London. £11.*

Papers given at the 1982 Symposium on Early Furnace Technology. The various contributions form a useful summary of the current research into early smelting. The following papers are included: R F Tylecote and J F Merkel: Experimental smelting techniques; achievements and future. J A Charles Determinative mineralogy and the origins of metallurgy. J R Maréchal (translated by P T Craddock): Methods of ore roasting and the furnaces used. W A Oddy and Judith Swaddling: Illustrations of metalworking furnaces on Greek vases. K T M Hegde and H E Ericson: Ancient Indian copper smelting furnaces. Suzanne Bernus and Nicole Echard: Metal working in the Agadez Region (Niger); an ethno-archaeological approach. N H Gale, A Papastamataki, Z A Stos-Gale and K Leonis: Copper sources and copper metallurgy in the Aegean Bronze Age. U Zwicker, H Greiner, K H Hofmann and M M Reithinger: Smelting, refining and alloying of copper and copper alloys in crucible-furnaces during prehistoric up to Roman time. Borislav Jocanovic: Smelting of copper in the Eneolithic Period of the Balkans. Beno Rothenberg: Copper smelting furnaces in the Arabah, Israel; the archaeological evidence. M Bamberger: The workings conditions of the ancient copper smelting process. J S Hodgkinson and C F Tebbutt: A fieldwork study of the Romano-British iron industry in the Weald of southern England. Elzbieta M Nosek: The Polish smelting experiments in furnaces with slag pits. R E Clough: The iron industry in the Iron Age and Romano-British period. E Photos, S J Filippakis, C J Salter: Preliminary investigations of some metallurgical remains at Knossos, Hellenistic to third century AD. P T Craddock, I C Freestone, N H Gale, N D Meeks, B Rothenberg and M S Tite: The investigation of a small heap of silver smelting debris from Rio Tinto, Huelva, Spain. Michael R Werner: The archaeological evidence for gold smelting at Kraku'Lu Yordan, Yugoslavia, in the Late Roman period. I C Freestone, P T Craddock, K T Hedge, M J Hughes and H V Paliwal: Zinc production at Zawar, Rajasthan.

PTC

G Demortier: Application de la méthode PIXE á la characterisation des alliages de soudure employés en bijouterie ancienne et antique. Les Cahiers de Physique Appliquée á l'Archéologie du CRIAA, Mai 1984,*Mai 1984,* **2,** *5-33.*Experiments carried out in the laboratory on soldering of ancient gold jewellery were based on Pliny's text (Vol 33,1). Cadmium sulphide was heated and dissolved in melted gold to make an alloy suitable for soldering. Demortier claims that in some cases the ancient craftsman made this type of alloy by collecting the yellow powder which is sometimes present on the surface of the zinc blende: a yellow powder which could be confused with chrysocolla is described by Pliny.

ECJT

H Forshell: Bronze cannon analysis. Alloy composition related to corrosion picture. *Armemuseum, 1984, Rapport No 2, 3-28.*

The structure and colour of the corrosion product on cast antique bronzes in an urban environment are conditioned by the underlying metal. AAS analysis shows considerable heterogeneity in the bronze due to micro- and macro-segregation of alloying elements with high density and/or low solidus point. The corrosion resistance of bronzes containing more than 10% of tin needs further study. Such bronzes may be identified occularly.

Author

J B Lambert, S V Simpson, S G Weiner and J E Buikstra: Induced metal-ion exchange in excavated human bone (variant uptake of various metals, eg lead, strontium (N Amer data)). *J Archaeol Sci, 1985,* **12,** *85-92.*

CBA

J Lang and M J Hughes: Soldering Roman silver plate (investigation by microscopy and XRF; experimental work). *Oxford J Archaeol, 1984, 3(3), 77-107.*

CBA

D A Scott: Periodic corrosion phenomena in bronze antiquities. *Stud Conserv, 1985,* **30,** *49-57.*

CBA

O D Sherby and J Wadsworth: Damascus steels (history; experimental production). *Sci Amer, Feb 1985,* **252***(2), 94-9.*

CBA

R J Taylor and I D Macleod: Corrosion of bronzes on shipwrecks. *Corrosion (USA), 1985,* **41***(2), 100-4.*

A comparison of corrosion rates deduced from shipwreck material after 170 years by electrochemical methods.

S Turgoose: The corrosion of archaeological iron during burial and treatment. *Stud Conserv, 1985,* **30,** *13-8.*

CBA

K Warren: World Steel: change and crisis. *Geography (No 307) 1985,* **70***(2), 106-17.*

Despite long-term continued expansion, by the early 1980s the world steel industry was in crisis and its geography was changing rapidly. The old industrial countries are rationalising their steel industries, while newly industrialising countries are making major extensions. The background and causes of these contemporary changes are surveyed. There is special reference to the USSR, the USA, India and China, Japan (a very successful producer without an adequate resource base), Europe and newcomers such as Brazil, Mexico, Argentina, Venezuela, South Korea and Taiwan and the threat of a trade war. Photographs and tables add to the value of this very important and informative paper.

PSR

G Weisgerber and C Roden, Römische Schmiedeszenen und ihre Gebläse. *Der Anschnitt, 1985, 37(1), 2-19.*

Discussion of possible development of bellows as depicted on stelae, sarcophagi and oil lamps from the West of the Roman empire with excellent illustrations of types. Comparisons made with modern Iranian bellows.

ECJT

BRITAIN

Anon: Stamp-charged coke; the end of an era. *Foundry Trade Journal, July 4 1985,* **159,** *(3309), 31.*

The closure of Coed Ely in 1983 brought to an end the production in Britain of this very dense and hard coke. Layers of crushed coal and straw were stamped together to make a solid coherent cake which was pushed bodily into the oven. The produce was ideal for iron melting cupola furnaces.

APG

D Austin and BC Burnham: A new milling and processing complex at Dolaucothi; some recent fieldwork results (med or early modern? need to reassess "Roman"). *Bull Board Celtic Stud, 1984, 31, 304-13.*

CBA

N Beagrie: The St Mawes ingot. Cornish Arch, *1983,* **22,** 107-11.

Discussion on the date of the H-shaped tin ingot (weight 72.5kg, c 99% Sn). An outline of the current evidence for the development of tin ingot size, shape and stamps within which the dating of the St Mawes ingot is considered. The author concludes that the ingot could be medieval in date.

B Bennison: A Middle Bronze Age looped plastave from Ollerton, Childs Ercall, Shropshire (trident pattern, Taunton/Cemmaes phase, analysis). *Proc Prehist Soc, 1984,* **50,** *386-8.*

W R Beswick, P J Broomhall and J D Bickersteth: Ashburnham blast furnace; a definite date for its closure (1813). *Sussex Archaeol Collect, 1984,* **122,** *226-7.*

CBA

T Bewick: Fire by night and fire by day; the growth of the cast metal trades in the West Midlands. *Foundry Trade Journal, July 18 1985,* **159,** *(3310), 79-91.*

The author attempts to provide some insight into the reasons why the West Midlands has the greatest concentration of foundries in the world today. Particular mention is made of the growth of the malleable-iron sector and the commencement of light alloy founding.

APG

N F Brannon: An examination of a bronze cauldron from Raffrey Bog, Co Down (corrects E T Leeds view). *J Ir Archaeol, 1984,* **2,** *51-7.*

CBA

S Briggs: The discovery and description of trench mines at Derricarhoon Td, Co Cork in 1846 (not prehistoric; "Derricarhoon trumpet" as powder horn?). *J Ir Archaeol, 1984,* **2,** *33-9.*

CBA

P T Craddock: Bronze Age Metallurgy in Brtain. Current Archaeology, *1986, 99, 106-9.*

Discusses the evidence for Bronze Age mining in Britain, particularly the grooved stone mining hammers and concludes that such mines as Alderley Edge, Shropshire and Mt Gabriel, Cork are Bronze Age. The absence of slag heaps on early sites in Western Europe compared to contemporary sites in the Mediterranean and the Middle East probably reflects the more sophisticated furnaces used in the latter area.

PTC

D Ford and J H Rieuwerts (eds): Lead Mining in the Peak District (history and guide to remains). *Bakewell: Peak Park Jt Planning Board 3. Received 1983. £3.95. (09075430X).*

CBA

J Goodridge: A new life for tin revival in Cornwall. *Geographical Magazine, August 1985, 424-9.*

A short background history of world tin extraction is followed by a description of the mining activities of Rio Tinto Zinc which took over two modern, but recently abandoned Cornish tin mines in 1979. The high price of tin made this an economic proposition. Modern large scale mining like that envisaged here should lower the costs of tin production. If present plans mature Cornwall will produce 5000 tons of tin in 1985 (half the record levels of a century or more ago) from five mines employing 1500 people. The paper beautifully illustrated by coloured photographs and maps. (Written just before the tin crisis - Abs Ed).

PSR

B K Herbert: The Field Walkers Guide and an Introduction to the Weald. Jan 1985. *Privately published from 1 Stirling Way, East Grinstead, Sussex RH19 3HG. £2.85.*

General description of the iron mines and smelting furnaces with reference to the Weald and some of the ways of recording and studying sites of iron production. A gazeteer of sites museums etc relating to the Wealden Iron industry is given.

PTC

J S Jackson: Copper mining at Mount Gabriel, Co Cork; Bronze Age bonanza or post-Famine fiasco? A reply (to C S Briggs). *Proc Prehist Soc, 1984,* **50,** *375-7.*

CBA

J S Jackson: The age of primitive copper mines on Mount Gabriel, West County Cork (upholds attribution to BA contra Briggs). *J Ir Archaeol, 1984,* **2,** *41-50.*

CBA

C E E Jones: A review of Roman lead-alloy material recovered from the Walbrook Valley in the City of London (tin or lead, not pewter). *Trans London Middlesex Archaeol Soc, 1983, 34, 49-59.*

CBA

M Mitchiner and A Skinner: English tokens, c 1200 to 1425. *British Numismatic Journal, 1983, 53, 29-77.*

Two hundred and thirty four tokens were analysed by energy dispersive X-ray fluorescence. Throughout the 13th century the tokens were made of pewter, usually the eutectic composition with about 62 percent tin and the balance of lead. However, there was then a change to lead as the most frequently used metal. Reasons put forward are the savings in cost and secular rather than ecclesiastical manufacture.

AATA

R Larn (ed): The wreck of the Dutch East Indiaman "Campen" on the Needles rocks, Isle of Wight, 1627 - Part 2. *Int J Naut Arch, 1985,* **14***(2), 97-118.*

Yielded 103 lead ingots, boat shaped, many of which are inscribed. These are listed here with a commentary by Lynn Willies. They have been "slashed" with an axe to assist loading and weigh about 60-70 kg. Although it is agreed that the marks are likely to be an indication of the smelter, the suppliers are unknown. Also deals with silver coins found in the "treasure".

RFT

F Pryor: Excavation at Fengate Peterborough, England. Fourth Report. *Northamptonshire Archaeological Society Monograph 2. Royal Ontario Museum Archaeology Monograph 7, 1985.*

A report on the scientific examination of the refractory and slag fragments from Iron Age contexts at Fengate, including crucible used for melting tin. By Dr P T Craddock.

I M Stead: The Battersea Shield, 1985, *British Museum Publication, £15.* Full description of this well known Celtic relic. Scientific appendices by H Barker, P T Craddock, M J H Hughes and S La Niece give analyses of the metalwork, enamels and finaly refutes the suggestion that the shield was ever gilded.

PTC

D Stewart: A medieval dagger and an iron missile point (Roman or med) in Swansea Museum. *Bull Board Celtic Stud, 1984, 31, 314-8.*

CBA

B Thomas: Iron making in Dolgellau (in 18th century). *J Merioneth Hist Rec Soc, 1984, 9, 474-5.*

CBA

R F Tylecote: The Historical Metallurgy Society and the history and prehistory of metallurgy in Europe. *Canadian Institute of Metals, 882, Historical notes, October 1985,* **78,** *75-7.*

A good article on the evolution and function of the HMS against the general development of the study of early metallurgy specifically by institutions in Britain and in the rest of Europe.

PTC

K Warren: Iron and Steel, *Geography (No 303), 1984,* **69***(2), 147-150.*

This paper deals with the rationalisation of the industry since the late 1860s. It describes the changes in sources of raw materials and markets; the decline in the amount of steel required by the British motor industry is especially noted. The author analyses the changes in the numbers of plants and the output; special emphasis is placed on the characteristics of the surviving plants and the future of Ravenscraig is discussed. Maps and Tables add to the value of this paper by a well known authority on the subject.

PSR

D Woodward: Swords into ploughshares; recycling in pre-industrial England. *Econ Hist Rev, 2 ser, 1985,* **38,** *175-91.*

CBA

R P Wright: Proposed expansion for the iron die found in, or before, 1889 in the City of London (MPBR — Metalla Provinciae Britanniae, ie lead?). *Britannia, 1984,* **15,** *257-8.*

CBA

EUROPE

H Born: Zur Technik und Restaurierung einer etruskischen Bronzeschnabelkanne. (Technique and restoration of an Etruscan bronze flagon). *Acta praehistorica et archaeologica, 1982,* **13-14,** *277-89.*

The technique of an Etruscan bronze flagon is described, as well as the restoration and conservation work performed on it. The analysis of the material is indicated. How to find the original antique surface between the corrosion layers on bronzes is explained.

AATA

H Born and A Mouszaka: Eine geometrische bronzestatuette im originalen Gussmantel aus Olympia. (A geometric bronze statuette in its original mould from Olympia, Greece). *Mitteilungen des Deutschen Archaeologischen Inst Athenische Abteilung, 1982,* **97,** *17-23.*

During a conservation campaign at the German excavations in Olympia, 1979, the author discovered a bronze statuette in the permanent exhibition of the New Museum in Olympia. The piece was still in its original mould as indicated by X-ray examination. A description of the research, opinions and a stylistic and temporal classification are presented.

AATA

F Beck, G Monthel and E Rabeisen: Note sur un moule à fibules de Bibracte (A brooch mould from Bibracte for casting 12 brooches at once, end 1st century BC). *Antiquities Nationales, 1982/3, 14/15, 78-85.*

CBA

P Benoit and Ph Braunstein (eds). Mines, carrières et métallurgie dans la France médiévale: Actes du Colloque de Paris, 1980. (Mining, quarrying and metallurgy in medieval France: proceedings of the Paris colloquium 1980). Paris. *Editions CNRS. 1983, 415pp, price 240FF, (paper 2 222 03057 9). (In French).*

Sixteen papers on historical and archaeological sources for mining and use of stone and metal.

CBA

J Briard: Paleométallurgie de la France Atlantique; Age du Bronze (2). (Paléométallurgy of Atlantic France; Bronze Age (2)). *1985, Rennes: Lab "Anthropol-prehist-protohist-quatern armoricaine", 189pp.*

CBA

I M Evans: Aspects of steel crisis in Europe with particular reference to Belgium and Luxembourg. *The Geographical Journal, 1980,* **146,** *(3), 396-407.*

The international steel industry has experienced severe recession since 1974. Heavy investment during previous years has resulted in considerable excess capacity, reduced output, declining prices and serious unemployment. Acute financial losses and a diminution in investment have also occurred. In Belgium and Luxembourg, there will be essentially two large groupings for future development, ie Cokerill and ARBED, other companies remaining independent and much smaller. Rationalization will occur within and between these poles, the state will play an increased role in their development and regional industrial reconversion will balance as far as possible the contraction in iron and steel. Illustrated by maps and tables.

PSR

J A Buckley: An analysis of thirty one coins from the Hellenistic period. *Archaeometry, 1985,* **27***(1), 102-7.*

Thirty one silver coins of the Hellenistic period were examined by the particle induced x-ray emission (PIXE) method, and the results incorporated into a wider study of the coins. Some tentative conclusions reached in the study are mentioned together with an outline of the PIXE method. A number of patterns emerged in the results, the most important being an apparent deterioration in silver content among the later Seleucid and Ptolemaic issues; some high concentrations of particular elements were also noted.

AATA

T Dannevig Hauge: Iron and steel in former times in Norway. *Bulletin of the Metals Museum of the Japan Institute of Metals, 1984,* **9**, *20-8.*

A detailed and up to date description of iron making in Norway concentrating on the smelting and forging of the iron.

PTC

G Gallay: Zu Fragen Bronzezeitlicher Nietung in Nordwestfrankreich. (Question of riveting in northwestern France). *Archaeologisches Korrespondenzblatt, 1983, 13(1), 49-57.*

To connect the blades of daggers with their hilts, peculiar types of rivets were used in the Bronze Age in Britanny. The rivets are surrounded by hulls of organic materials usually bone or wood. The definition of a rivet is discussed; strictly speaking, the metal pieces used to connect the two parts are pins, which permit a separation of parts without destroying them. while a rivet has to be broken, if joined parts are separated.

AATA

E Formigli: Uebernommene und neu entwickelte Verbindungstechniken im etruskischen Metallhandwerk. (Traditional and newly developed techniques of joining Etruscan metal objects). *Arbeitsblaetter fuer Restauratoren, 1984, 17, H.1, Gr2, 138-60.*

The scientific examination of Etruscan objects revealed a variety of joining techniques used on metal tools and weapons as well as statuettes. For the manufacture of chains, peculiar techniques of casting were employed. Different techniques of soldering could be observed.

AATA

A Madronero de la Cal: The beginning of iron smelting and forging in the ancient Iberian peninsula. *Bulletin of the Metals Museum of the Japan Institute of Metals, 1985,* **10**, *26-34.*

A speculative account of early iron technology in the Iron Age and Roman Spain. Claims that statuettes were cast from fayalite.

PTC

J Harrison: Heavy industry; the state and economic development in the Basque region, 1876-1936. *The Economic History Review, 1983,* **36***(4), 535-51.*

The part played by the discovery of the Bessemer process in 1856 which made possible the utlisation of hematite ore near Bilbao is described in some detail. A useful table shows the rising production and exports in the period. The re-investment of profits from iron ore into the establishment of a modern large scale iron and steel industry, based on Welsh coal (exchanged with iron ore) is noted. The fluctuating output of iron ore and the efforts of the state to promote the industry are discussed.

PSR

J Lang and R Holmes: Studies on the technology of beaded rims on Late Roman silver vessels. *Britannia, 1983,* **14**, *197-206.*

Beading is a familiar technique on Roman silverware; examination of ancient plate and experimental work are used to reconstruct the techniques. Generally, the beaded rims were made by stamping the folded rims with individual dies.

AATA

I Jenkins: A group of silvered-bronze horse-trappings from Xanten (Castra Vetera). *Britannia, 1985,* **16**, *141-64.*

Full account of the discovery of this important group. They are fully described and illustrated, their function and parallels with other groups are discussed in detail. An appendix by P T Craddock and J R Lambert gives the AAS analyses of the metalwork. They are all brass of consistent composition. The broader implications of the use of good quality brass by the army is discussed.

PTC

I Keesmann: Chemische und mineralogische Untersuchung von Eisenschlacken aus der Hallstattlichen Siedlung von Niedererlbach. (Chemical and minderalogical investigation of iron slags from the settlement of Niedererlbach of the Hallstatt period). *Arch Korrespondenzblatt, 1985,* **15***(3), 351-7.*

Electron probe microanalysis (EPMA) was done on these slags and it was concluded that they came from a smithing process. Full composition of 6 slags are given together with microstructural features.

RFT

E Munksgaard: A Viking smith, his tools and his stock-in-trade (Tjele hoard 1850, includes helmet nasal and eyebrows). *Offa, 1984, 41, 85-9. Further material from hoard, pp91-6.*

CBA

R Pittioni: Uber Handel im Neolithikum und in der Bronzezeit Europas. *Abhandlungen der Akad den Wissenschaften in Gottingen, 1985,* **143***(3), 127-80 and* **143***(4), 152-63.*

S Rovira Llorens and M S Sanz Najera: Estudio Arqueometalurgico de las Piezas metalicas de El Penon de la Reyna (Alboloduy, Almeria). (Archaeometallurgical study of metallic objects from El Penon de la Reyna, Almeria). *Antropologia y paleoecologia humana, 1983,* **13,** *139.202.*

The quantitative and metallographic investigation carried out on 20 copper-base objects (tin-bronzes and arsenical coppers) found in El Penon de la Reyna some conclusions are obtained from the metallurgical technology in the Middle and Late Bronze Age in the South East of the Iberian Peninsula. Results are related to Tartessian and East Mediterranean bronzes.

Authors

G Sperl: Die Technologie des ferrum Noricum. Hermann Vetters Festschrift in: Lebendige Altertumswissenschaft, Wien, 1985, 410-6.

A detailed and all-embracing enquiry into the problem of the definition and quality of iron. The author throws light on all aspects of the subject starting with the geographical position and changing boundaries. Types of mines and quality of ores are discussed, as well as furnace construction, types of slags and the many smithing hearths. Comparisons are made with furnaces from Siegerland and Burgenland etc. Many pieces of cast iron were found at Magdalensberg with ledeburite structures and indicating the iron ores used often had a high phosphorus content. Objects from Hallstatt show that high carbon iron was available there too. Although investigation of technology and working processes could be established, the exact origin of the ore and the method of production of the raw bloom is not yet established. Further work is necessary to answer some questions satisfactorily.

ECJT

K Lundblad and M Törnblom: Kemisk analys av Helgobronser. (Chemical analyses of bronze objects from Helgo in Uppland). *In book Konserveringstekniska studier, Civiltryck AB, Stockholm, 1983, 35-48. (In Swedish, with Swedish-English summary).*

Seventy one copper alloy objects from Helgo, Ekero parish in Uppland, have been chemically analysed using x-ray fluorescence spectrometry and atomic absorption spectrophotometry. The artefacts included 11 bars, 12 rods, 8 foils, 7 brooches, 1 buckle, 7 ingots, 5 metal fragments from crucibles and 20 weights.

AATA

I Serning: The dawn of the Swedish iron metallurgy. *Bulletin of the Metals Museum of the Japan Institute of Metals 1984,* **9,** *3.19.*

A detailed and up to date description of the origins of Swedish iron making concentrating of the periods before 1000 AD.

PTC

A J V Vaamonde, L de L Martin et al: Technical analysis following the discovery of Bronze axes. Part II. *Fundición, Sept 1984,* **30,** *29-34. (In Spanish).*

W J H Willems and J Ypey: Ein Angelsachsiches schwert aus der Maas bei Wessem, Provinz Limburg (Niederlande). (An Anglo-Saxon sword from the Maas at Wessem, Netherlands. Trewhiddle cfs, 9th century: inlay analysis). *Archaöl Korrespondenzblatt, 1985,* **15,** *103-13.*

CBA

AFRICA

P T Craddock and J Picton: Medieval copper production and West African bronze analysis. Part II. *Archaeometry, 1985,* **28***(1), 17-41.*

Reports the analyses of about 200 bronzes from West Africa, now principally at the Museum of Mankind, London. The development of copper alloys in West Africa is discussed suggesting that the 10th century Igbo-Ukwu bronzes were made from locally produced metal with no outside influence. The various groupings and styles of late metalwork is initially compared to the composition of the bronzes in the group. Suggests there is little correlation. A technical exmination of the Benin bronzes is given in a long appendix on the casting technology.

PTC

P Richardson and J-J Van Helten: Surveys and speculations, XXIII. The development of the South African gold-mining Industry, 1895-1918. *The Economic History Review, 1984,* **37***,(3), 319-40.*

Within twenty years of the original discovery of gold on the Witwatersrand in 1886 South Africa became the world's largest single producer of gold. As part of the survey of the current literature on this subject this article demonstrates that while the dramatic impact of this discovery upon developments in South Africa has been the subject of much debate, little attention has been paid to the changing economic structure of the gold mining industry itself. Corporate mining behaviour, the transformation from outcrop to deep-level mining and structural changes within the industry are considered in detail. The authors suggest that although the group system of mining represented a highly centralised structure of ownership and control within the industry, no simple equation between ownership and deep-level mining existed. The development of the South African gold mining industry was far more complex; capital accumulation on the Rand was a dynamic process of collusion and competition.

PSR

AMERICA

Anon: Aluminium casting caps Washington Monument. *Foundry Trade Journal, July 18, 1958, 159, (3310), 48-9.*

In 1884 a 100oz square-based pyramid of aluminium was secured into position on top of the marble capstone surrounding the Washington monument. It was at the time the largest piece of aluminium ever cast. The metal was made by the Deville process, based on sodium reduction and contained 1.7% silicon and 0.55% iron. It acts as the tip of the lightning conductor system.

APG

W Burgess: Recent mining developments in the Canadian arctic. *Geography (No 198), 1983,* **68,** *(1), 50-3.*

Although the oil industry is of major importance, the high cost of working in such a remote and challenging environment does not appear to have deterred mining companies; gold, silver, zinc and lead are the main metals extracted. The writer discusses mining problems, transport (use of aircraft) and communication (satellite) in some detail. The paper is illustrated by a useful map.

PSR

D A Scott: Gold and silver alloy coatings on copper. *Archaeometry, 1986,* **28***(1), 33-50.*

A detailed metallographic and analytical study of gilding on copper base artefacts probably from Equador and Columbia. May have been gilded by the so-called work-gilded or fusion gilding technique, the base metal was heated and treated with a molten copper-gold alloy to produce the plated layer which could then be burnished and itself depletion gilded to give a fine gold colour.

PTC

ASIA

D Donaldson: Prehistoric tombs of Ras Al Khaimah. *Oriens Antiquus, 1984,* **24,** *191-312.*

Detailed scientific studies of the material from the tombs, including the metal work. AAS analyses by P T Craddock showed an interesting range of alloys. Much of the copper had an appreciable nickel content. The relevance of this to the old problem of the origin of the copper used by the Summerians which also has a high nickel content is discussed.

PTC

P Gatrell: Industrial expansion in Tsarist Russia, 1908-14. *Economic History Review, 2nd Series, 1982,* **35**(1), 99-110.

Although a wide ranging paper it contains material on the Russian metallurgical industry, especially on the output of iron and steel and how far this was used in armaments, railway construction and consumer goods. Contains useful tables.

PSR

H Mabuchi, Y Hirao and M Nishida: Lead isotope approach to the understanding of early Japanese bronze culture. *Archaeometry, 1985,* **27***(2), 131-59.*

For several years, the authors have used lead isotope analysis to investigate the provenance of ancient or copper artifacts which had been excavated mainly from Japanese archaeological sites. The results have been published item by item in several relevant Japanese journals. This review is intended to give an account which will review the whole work relating early Japanese bronze culture to Chinese and Korean cultures through lead isotope studies.

Author

A Raban and E Galili: Recent maritime archaeological research in Israel — A preliminary report. *Internat Journ Naut Arch and Underwater Explor, 1985,* **(4)**, *321-54.*

Ingots of various types are still being found off the coast of Israel south of Haifa. A wreck of a merchantman has produced a stone anchor inscribed with an Egyptian scarab and an LBA sickle-shaped bronze sword. 8 tin ingots were also found nearby; some were bar-shaped, about 50 cm long, another was a plano-convex ingot weighing, when complete, 36kg. There were also some smaller plano-convex and rectangular lead ingots. The best estimate for the date is 14th-13th century BC.

RFT

W Rostoker, M B Notis, J R Dvorak and B Bronson: Some insights on the "Hundred Refined" steel of ancient China. *Masca Journal, 1985, 3(4), 99-103.*

S Rai, N Rajan and M Singh: Some aspects of Iron Age in ancient India; an archaeo-technological study. *Bulletin of the Metals Museum of the Japan Institute of Metals, 1985,* **10,** *35-9.*

A general survey of origins of iron making in India and a detailed examination from some iron artefacts excavated from megalithic sites in southern India. Chemical analysis, XRD, Mossbauer spectroscopy and SEM examination were all used.

PTC

N N Terekhova: ironworking in early Mongolian towns. *Sov Arch, 1985, (3), 72.80.*

Archaeological investigations in the Mongolian People's Republic and in the southern trans-Baikal region headed by Sergei Kiselyov proved the existence of towns in early Mongolian society but also demonstrated their considerable role as centers of handicrafts etc. The iron objects from Karakorum and the old Mongolian town of Khirkikira in the southern trans-Baikalian area were analysed. The investigations showed that local blacksmiths used various kinds of raw materials: iron, raw and case-hardened steel. Early Mongolian smiths were experts in the forging of metal, knew how to weld iron and steel and used heat-treatment, riveting and brazing.

Author (abridged).

Ton-Suk Yun and K Kubota: A survey of the sites of ancient iron making places near Chung-ju City, Korea. Bulletin of the Metals Museum of the Japan Institute of Metals, 1984, 9, *31.*

Includes analyses of iron ores and slags.

PTC

Noel Barnard: "Wrought metal-working prior to middle Shang (?) - A problem in archaeological and art-historical research approaches", *Early China (Berkeley), 1980/81,* **6:***4-30.*

Robert W Bagley and others contend that the earliest Chinese bronzes were made by smithy methods; though no ancient wrought-bronze artifacts have been found in China, it is supposed that this earliest phase had a significant influence on the style of later cast-bronzes artifacts. Barnards refutes this contention.

DBW

Yang Kuan: Zhongguo gudai yetie jishu fazhan shi (The history of the development of siderurgical technology in ancient China), *Shanghai: Renmin Chubanshe, 1982.*

A technical and cultural history from the earliest times to the twentieth century.

DBW

Cao Tengfei, Li Caiyao: Guangdong Luoding gu yetielu yizhi diaochab jianbao (Survey of ancient iron-smelting furnace sites in Luoding County, Guangdong, China), *Wenwu (Cultural relics), 1985.12:70-74.*

Luoding is mentioned in a 17th century account as a place which was especially famous for its iron production (Guangdong xinyu by Qu Daxin, Hong Kong 1974 ed, ch 15, pp 408-410). Brief surveys were conducted here by the Guangdon Provincial Museum in 1978 and 1982. There are numerous villages in Luoding whose names include the character *lu,* "furnace"; slag tips and remains of blast furnaces were found near most of these. Apparently pig-iron produced in these villages was transported overland to a place called Datangji, whence it was shipped downriver to the great industrial city of Foshan, Guangdong.

One furnace, in the village of Luxia ("Below the furnace"), was investigated; it is believed to date from the 17th century. The furnace was built against a mountainside for ease in charging, and therefore its original height can be estimated as 6-8 m, of which 3 m remains. The furnace is a "trumpet" with elliptical cross-section, 86 x 96 cm at the hearth, 149 x 343 cm at a height of 3 m. A weir about 500 m from the furnace seems to have been used in water-powered ore-crushing; whether water-power was used for the blast could not be determined.

A small fining hearth was also found nearby, but was not excavated. Analyses of one of two iron bars found gave:

C	S	P	Si	Mn	
0.07	0.007	0.0029	0.15	0.06	%
			0.08		
			0.03		

DBW

Chen Shixian, Xiong Xianming: Zhongguo gudai zuanya jishu yingyong chukao (a preliminary investigation into the use of metal spinning techniques in ancient China) *Ziran kexue shi yanjiu (Studies in the history of natural sciences), 1985,* **4.4***:342-344.*

The authors investigated three silver vessels of the eighth century AD from a buried hoard in Xi'an, Shaanxi. Two were formed by hammering, while the third appears to have been formed roughly by hammering and then finished by spinning.

DBW

Chen Wenhua: Cong chutu wenwu kan Han dai nongye shengchan jishu (The agricultural technology of the Han period (206 BC — AD 220) in the light of archaeological finds), *Wenwu (Cultural relics), 1985.8:41-48.*

Includes discussion of iron implements and their functions. Numerous illustrations.

DBW

Chen Yingying, Jia Meixian: Guowai xuezhe yanjiu Tang dai jin yin qi qingkuang jieshao (Introduction to research by foreign scholars on Tang-period (AD 618-907) gold and silver artifacts), *Kaogu yu wenwu (Archaeology and cultural relics), 1985.***2***:74-81.*

DBW

Gudai tonggu xueshu taolun hui lunwenji (Symposium on the bronze drums of ancient south China), *Beijing: Wenwu Chubanshe, 1982.*

Includes:

Tang Wenyuan: Guanyu tonggu jiadian zhuzao gongyi de tantao (On the use of chaplets in the casting of the bronze drums), *pp 192-200.*

Bronze coins were used to separate the core from the cope, and their original patterns can often be seen on the surface of the finished drum.

DBW

He Tangkun: Guanyu gu jing biaomian touming ceng de kexue fenxi (A scientific analysis of the transparent coating on the surface of ancient Chinese mirrors), *Ziran kexue shi yanjiu (Studies in the history of natural sciences), 1985,* **4***.3:251-157.*

A number of ancient mirrors have been found which have a transparent anticorrosive film; some were still perfect mirrors when excavated.

Four mirrors, probably 1st-2nd century AD, were studied. Their bulk analyses were:

	Cu	Sn	Pb	Zn	
E15	70.43	23.95	5.38	0.007	(Wet analysis)
E55	75.773	20.225	4.001		(electron mocroprobe)
W7	70.4	24.80	5.90		(electron absorption spectroscopy)
W11	77.197	21.681	1.120		(electron microprobe)

Electron microprobe analysis shows that the transparent film is ca 10 microns thick, with 69-76% Sn, 8-16% Cu (more details in article).

The author reviews several techniques for surface treatment of mirrors which are known from ancient texts. None of these seems to be relevant to the present case, but they show clearly that very complex processes were in use in very early times. He suggests that the treatment used here may have been similar to a modern glazing technique in which the object is coated with $(CH_2)_2SnCl_2$ and annealed at 600°C to give a surface film of $Sn0_2$.

DBW

Keightley, David N (ed): The origins of Chinese civilization. *Berkeley/Los Angeles/London: University of California Press, 1983.*

Includes:

Noel Barnard: "Further evidence to support the hypothesis of indigenous origins of metallurgy in ancient China", pp 237-278.

Ursula Martius Franklin: "On bronze and other metals in early China", *pp 279-296.*

DBW

Liu Haichao: Anhui Yingshang Wanggang, Zhaoji faxian Shang dai wenwu (Artifacts of the Shang period (ca 1600-1100 BC) discovered at Wanggang and Zhaoji in Yingshang County, Anhui, China), *Wenwu (Cultural relics), 1985.***10***:36-41.*

A review of chance finds in this area called to the attention of the local museum since 1972. The finds include a remarkable number of *lead* imitations of bronze vessels.

DBW

Luo Yixing: Lun Ming Qing shiqi Foshan chengshi jingji de fazhan (The development of the urban economy of Foshan, Guangdong, China, in the Ming and Qing periods), *Zhongguo shi yanjiu (Studies in Chinese history), 1985.***3***:109-123.*

Foshan, about 15 km from Guangzhou (Canton), was until about the time of the Opium War a great industrial centre for all of south China. It was among other things a major producer of fine steel and cast-iron products which were marketed all over China and southeast Asia. This article traces the economic development of the city with particular attention to the iron industry.

DBW

Shang Zhou kaogu (The archaeology of the Shang and Zhou periods (ca 1600 - 256 BC)), *Beijing: Wenwu Chubanshe, 1979.*

The standard Chinese university textbook on all aspects of Shang and Zhou archaeology. On bronze casting techniques see pp 43-47, 168-171, 250-257; on iron-smelting, pp 234-239.

Note the rather negative review by Robert Thorp and the rejoinder by David W Goodrich (*Early China* (Berkeley), 1980/81, **6**:97-102; 1981/82, **7**:38-45).

DBW

Song Zhimin: Han dai de tongqi zhuzao shougongye (The craft of bronze casting in the Han period (206 BC — AD 220)), *Zhongguo shi yanjiu (Studies in Chinese history), 1985.***2***:13-25.*

A review of archaeological and written evidence concerning: (1) the applications of bronze in the Han period; (2) relations of production; (3) production and supply of raw materials.

DBW

Hou Dejun: Chu ren de caijin fangfa (Gold-extraction methods in the ancient Chinese state of Chu (pre-3rd century BC)), *Jiang Han luntan (Forum for the Changjiang – Hanshui region), 1985.***3***:72.*

Brief note on some archaeological and written evidence.

DBW

Wang Haiwen: Qiantan qingtongqi de baoguan (A note on the conservation of bronze artifacts), *Gugong Bowuyuan yuankan (Palace Museum journal), 1985.***2***:74-78.*

DBW

Liu Xing: Dongnan diqu qingtongqi fenqi (Typological chronology of the bronze artifacts of southeast China), *Kaogu yu wenwu (Archaeology and cultural relics), 1985.***5***:90-101.*

The bronzes of this region are especially worthy of the attention of archaeometallurgists for at least two reasons: (1) it is the only part of China in which bronze agricultural implements have been found in significant numbers; (2) according to the best guess possible today, this is where iron was first used in China.

DBW

Xie Shiping: Han dai de jianqian gongyi (The technique of coin-clipping in the Han period (206 BC — AD 220)), *Zhongyuan wenwu (Cultural relics from Central Plains), 1985.***1***:89-90.*

Discussion of some clipped coins and the shears used in clipping them.

DBW

Zhou Nanquan: Ming Qing gongyi meishu mingjiang (xu) (Famous art craftsmen of the Ming and Qing periods (AD 1368-1912), continued), *Gugong Bowuyuan yuankan (Palace Museum journal), 1985.***1***:83-96.*

pp 87-89: Bio-bibliography of 59 metal-workers. Photographs of four remarkable "iron paintings" by the 18th century blacksmith Tang Peng.

DBW

Xu Xianguo: Echeng xian faxian yichu gu yelian yizhi (An ancient smelting site discovered in Echeng County, Hubei, China), *Jiang Han kaogu (Jianghan archaeology), 1985.***4***:80.*

Brief plea for renewed interest by archaeologists in the site of an open-cast copper mine and a nearby site at which large amounts of copper-smelting slag have been found. The place is known locally as Tongzao, "copper hearth", and tradition takes copper-smelting here back to the fourth century AD. Unpublished material from an excavation in 1950 suggests that smelting may actually have taken place here as early as the sixth century BC or before.

The site is only 40 km from the famous Tonglüshan ancient copper-mine site (on which see JHMS **20.1**:) and the author suggests that operations at Tongzao may have been on an even larger scale than at Tonglüshan.

DBW

Zhang Hongli: Zeng hou Yi bianzhong fuzhi yanjiu huo zhongda chengguo (Important results obtained in simulation experiments concerning the chime bells of Marquis Yi of Zeng), *Zhongguo keji shiliao (China historical materials of science and technology), 1985.* **6.***2:56.*

Brief journalistic account of experimental simulation of the casting techniques used for these bells of the sixth century BC.

ABSTRACTS

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