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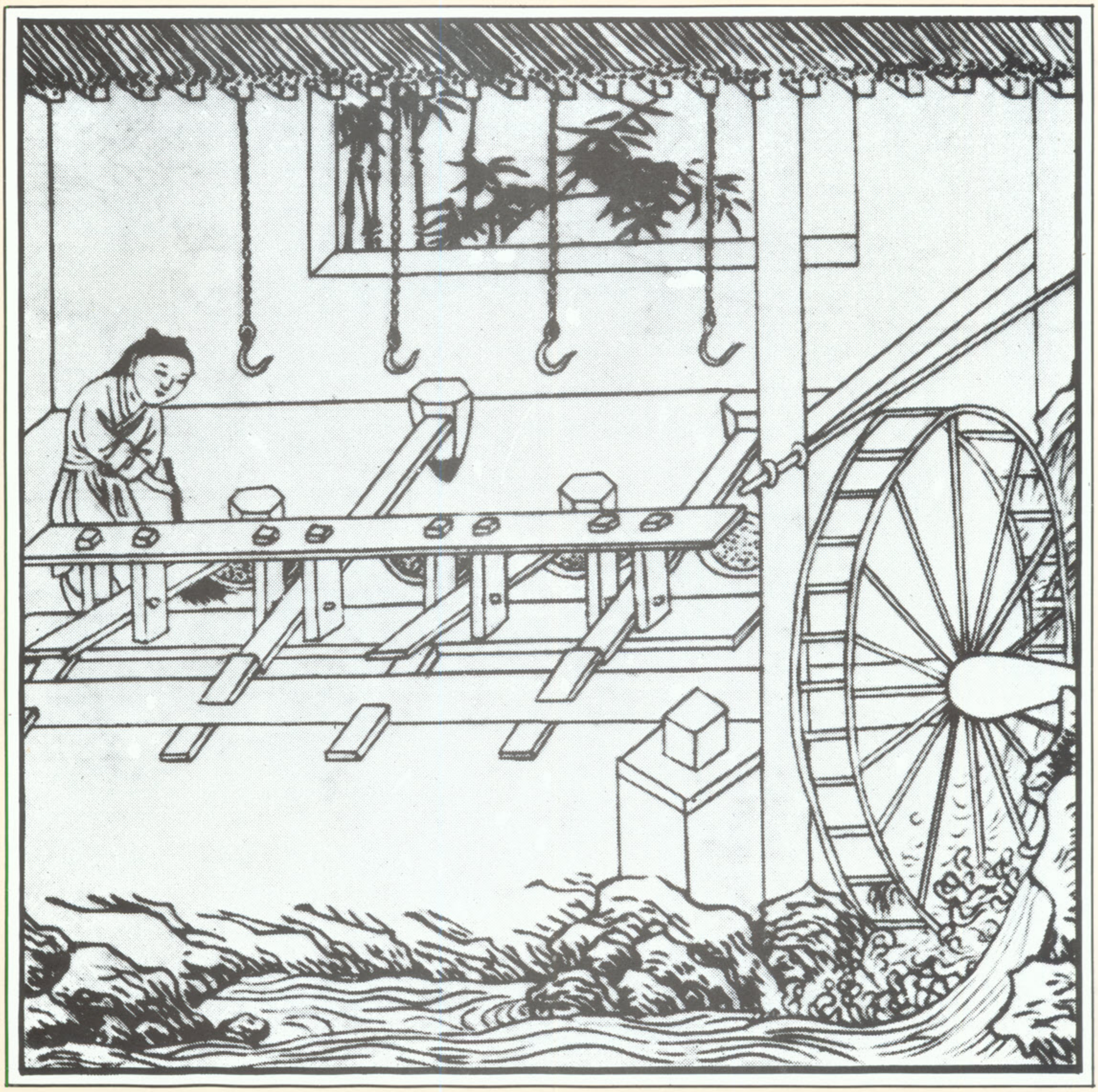

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Contents

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Copper and Bronze Metallurgy in Sardinia

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Abstract

A survey of the mineral and metal resources of the island of Sardinia has been undertaken by a metallurgist, archaeologist, and geologist in a collaborative effort to define and treat the problems of the significance of metal technology and trade for the Bronze Age nuragic populations. The first verifiable smelting slag has come to light; its appearance in a hoard of ancient tin confirms local smelting as well as casting. Combined with increasing evidence for early interaction with Mycenaeans and Phoenicians, these finds support a concept of Sardinia as an emporium after 1200 BC in dramatic contrast to the notion of withdrawn isolation held only one decade ago.

Introduction

Copper and tin, the main components of bronze, have been the focus of continuing studies to determine their source, the technology of the mining and smelting of their ores, the methods of casting, and their place in trade among the different cultures and civilizations of the ancient Mediterranean. The island of Sardinia has emerged as an increasingly important site for these studies because of the natural resources which drew prospectors from other lands, and finds which were suggestive of an extensive metal-working industry. In just the last ten years, continuing excavation and research has changed the conception of the island from an isolated backwater to an emporium in the mainstream of the Mediterranean, especially after 1200 BC[1].

In 1976, the problem of Sardinia's metal resources and their exploitation was first discussed on these pages, along with the analyses of the three copper 'oxhide' ingots plus a handle of a fourth, in the Museo Archeologico Nazionale in Cagliari. There is copious evidence for a casting technology during the Sardinian Bronze Age, also called 'nuragic', after the thousands of towers known throughout the island and lasting roughly from 1500 to 500 BC, but the presence of the 'oxhide' ingots, better known from contexts in the Aegean, presented the problem of whether they had been locally produced or imported. Since that time, more and more ingots have been found, with the result that there are more findspots for them in Sardinia, usually cut up into pieces, than from anywhere else in the Mediterranean, and they have been known there longer, since 1858 !

The need for further research was one of the conclusions in our earlier report[2] and one purpose of this communication is to report the progress of some of the work undertaken . In addition, with the added collaboration of a Sardinian geologist, it has been possible to survey the mineral and metal sources of the island and to analyze more metal with more conclusive results.

The main problem in regard to early metallurgy in Sardinia is one in common with most of the Eastern Mediterranean, that is assessing the extent to which the island used its own indigenous supply of minerals and calculating how much was imported. There is no doubt that by the Later Bronze Age the use of metals in Sardinia was as great or greater than that elsewhere and that there is evidence for import or trade in the existence on the island of copper 'oxhide' ingots containing so-called 'cypro-Minoan' inscriptions common in the Aegean area [2,3,4]. This invites the question: 'Was the supply of copper in the Late Bronze Age inadequate to meet the needs of the community, requiring imports, or was it so great that there was a surplus for export in the form of an internationally acceptable ingot type?'

The following discussion is an attempt to assess the supply and demand situations in the Copper and Bronze Ages and to shed light on the prospects of import and export trade.

A. Previous Work

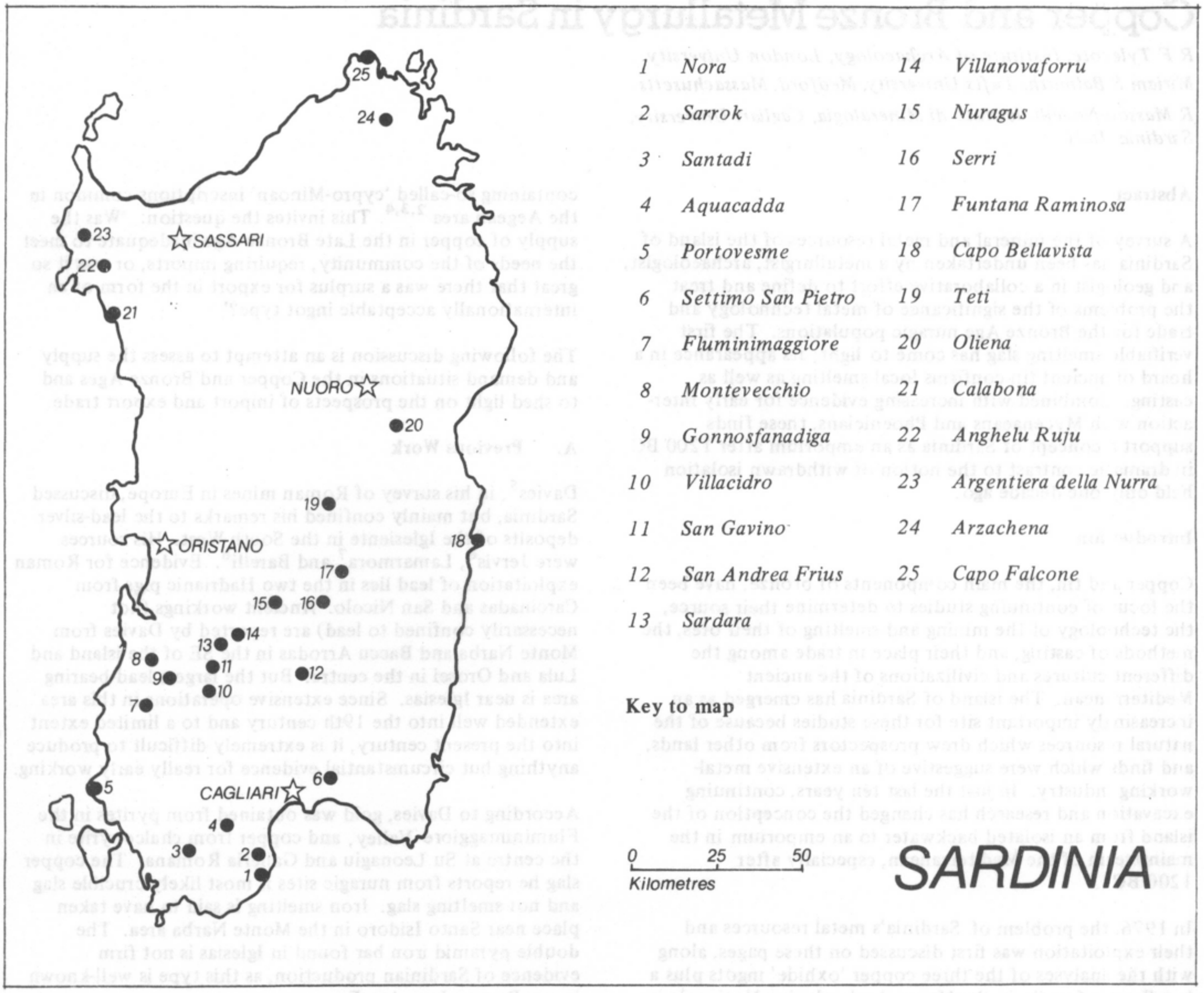
Davies[5], in his survey of Roman mines in Europe, discussed Sardinia, but mainly confined his remarks to the lead-silver deposits of the Iglesiente in the South-West. His sources were Jervis[6], Lamarmora[7] and Barelli[8]. Evidence for Roman exploitation of lead lies in the two Hadrianic pigs from Carcinadas and San Nicolo. Ancient workings (not necessarily confined to lead) are reported by Davies from Monte Narba and Baccu Arrodas in the SE of the island and Lula and Orosei in the centre. But the largest lead-bearing area is near Iglesias. Since extensive operations in this area extended well into the 19th century and to a limited extent into the present century, it is extremely difficult to produce anything but circumstantial evidence for really early working.

According to Davies, gold was obtained from pyrites in the Fluminimaggiore Valley, and copper from chalcopyrite in the centre at Su Leonagiu and Galleria Romana. The copper slag he reports from nuragic sites is most likely crucible slag and not smelting slag. Iron smelting is said to have taken place near Santo Isidoro in the Monte Narba area. The double pyramid iron bar found in Iglesias is not firm evidence of Sardinian production, as this type is well-known in pre-Roman Iron Age Europe.

One of the principal metallurgical sites cited by previous authorities is the so-called **fonderia** at Ortu Comidu excavated by Taramelli and published by him in 1918[9]. This site has now been re-examined and found to have little metallurgical significance [10]. The large structure (Dia.lm) thought by Taramelli to be smelting furnace was found not to have been heated above 800°C. It may have been originally nuragic, but this is still uncertain; it was surely used by the Carthaginians and is probably concerned with some domestic process such as baking. It contains no metallurgical contamination.

Some of the moulds and ingots found on the island are described and illustrated by Zervos, and have now been treated more fully by Becker [11]. Specimens have clearly been taken from some of the ox-hide ingots for analysis but we can find no trace of the results. Many objects and some plano-convex ingots have been analysed by Junghans et al and are reported in SAM. [12]

The rest of the evidence for Sardinian metallurgy resides in the Museo Archeologico Nazionale at Cagliari, the Museo Nazionale 'G A Sanna' at Sassari, and the Museo Civico Speleo-Archaeologico at Nuoro, or in collections abroad. The amount of material is considerable, and this itself is sufficient evidence for a well-developed Bronze Age metallurgy. Unfortunately, while much of it is provenanced, little of it is stratified.



Key to map

1	*Nora*	14	*Villanovaforru*
2	*Sarrok*	15	*Nuragus*
3	*Santadi*	16	*Serri*
4	*Aquacadda*	17	*Funtana Raminosa*
5	*Portovesme*	18	*Capo Bellavista*
6	*Settimo San Pietro*	19	*Teti*
7	*Fluminimaggiore*	20	*Oliena*
8	*Montevecchio*	21	*Calabona*
9	*Gonnosfanadiga*	22	*Anghelu Ruju*
10	*Villacidro*	23	*Argentiera della Nurra*
11	*San Gavino*	24	*Arzachena*
12	*San Andrea Frius*	25	*Capo Falcone*
13	*Sardara*		

B. Minerals and Mineral Deposits

A recent map of the geology and ore deposits of Sardinia[13] shows a fairly widespread mineralization but most of this is in the palaeozoic rocks of the centre and the south-west. Much of that elsewhere is of minor importance and the extent of exploitation by man seems doubtful apart from the copper deposit of Calabona near Alghero.[14]

If, for the present, we confine ourselves to the known occurrences of economically exploitable ores, we find lead-zinc and copper ores in the Iglesiente, copper-lead-zinc ores at Funtana Raminosa in central Sardinia, copper in Calabona and cassiterite in the Iglesiente, discussed in this order:

(1) **Lead-zinc ores in the Iglesiente.** Here there has been extensive exploitation from the Roman times onwards. From an ore deposit point of view, we find two types of Pb-Zn mineralization in the south-west area; a sedimentary-re-mobilized series of deposits (Masua, S Giovanni, Monteponi, etc) linked to the Cambrian limestones (the so-called 'Metalliferous') and the vein type, hydrothermal deposit of Montevecchio, formed during the Hercynian orogenesis. Both deposit types are well oxidized on the surface. One item of interest from this area is the high bismuth and silver contents of the galena which in some mines are still running at 0.6% Bi and 0.15% Ag. The silver content, especially in the Montevecchio and S Giovanni mines, is nearly as high as that of the famous Laurion deposits of Greece[15]. From an economic point of view Masua is today one of the most important Pb-Zn deposits in Italy.

Modern smelting operations involve the zinc-lead plant at Portovesme (Imperial Smelting) which is smelting the zinc-lead concentrates of Masua (about 600 t/day), some from other Iglesiente deposits and others imported. In S Gavino is a lead smelter which is refining the lead by-product from Portovesme and smelting small amounts of galena from the deposits at Montevecchio and elsewhere (Table 1).

(2) **Copper in the Iglesiente.** Copper in the Iglesiente area is not a common metal: it is much diffused in the Silurian ores in the centre area of Sardinia (Funtana Raminosa). In the Iglesiente the only deposit with copper is Rosas, still exploited. Smelting used to take place at Rosas and there are still some old disused roasting furnaces there. The most important deposit at Rosas is called 'Sa Marchesa' it is a Cu-Pb-Zn mineralization included in the Metalliferous Cambrian limestones formation. The pure and compact limestones are transformed, probably by a deep granitic Hercynian intrusion, into a saccharoid marble,

while the impure and finely stratified limestones are, on the other hand, transformed into a skarn, characterised by garnet, diopside, wollastonite, epidote, and calcite.
A mineralographic study of Venerandi Pirri[16] shows the presence of the following ore minerals: sphalerite, galena, chalcopyrite, pyrite, arsenopyrite, marcasite, cobaltite, pyrrothite, mackinawite, bismuthinite, molybdenite, hematite, magnetite, bornite and stannite.

Table 1

Output and composition of ore from Montevecchio Mine in 1979

	Weight tonnes	Composition %				
		Pb	Zn	Ag(ppm)	Cd	Bi
Total input to Concentrator	113,000	1.71	3.04	-	-	-
Galena	2,365	75.58		419		0.0035
Blende	4,885	-	59.76	-	0.45	-
Tailings	105,750					

(3) **Exploitation of copper-lead-zinc ores at Funtana Raminosa in central Sardinia.** Ores seem to be linked to a 'skarn' rock with silicified limestones, but recent studies have pointed out the importance of the volcanism in the Silurian sedimentary sequence and the connection between this volcanism and the ore deposits. After the three principal sulphides, other ore minerals are: pyrite, cobaltite, cubanite, pirrotina, mackinawite, marcasite, bornite, magnetite. The ore yields 1% Cu, 1.5% Pb and 3.5% Zn and is concentrated to give three fractions, containing respectively 26% Cu, 50% Pb and 48% Zn (Table 2).

Table 2

Output and Composition of ore from mine at Funtana Raminosa for 1979

Product	Quantity and Composition %					
	Tonnes	Cu	Pb	Zn	Ag	Cd
Raw ore	44,800	0.76	0.77	2.10	0.00646	-
Chalcopyrite	1,012	26.65	5.04	4.43	0.099	-
Galena	467	2.98	50.31	8.75	0.1454	-
Blende	1,567	2.12	0.64	48.40	0.0112	0.97
Tailings	41,754	0.05	0.12	0.23	0.00137	-

As far as the trace elements are concerned, the chalcopyrite contains 1000g/tonne (0.1%) of silver and 0.1% As; the galena, 1400g/tonne silver (0.14%) and the blende (ZnS) 10kg/tonne (1.0%) Cd and 120g/tonne silver. It is interesting that the silver content of the galena is about the same order as that shown for the galena in the Iglesiente and that this must be a general characteristic of the Sardinian deposits. The occurrence of cadmium in zinc is fairly normal but the presence of bismuth in the galena is not so, and has necessitated the use of electrolytic refining at San Gavino rather than the more normal fire refining in kettles.

Like the copper ore from Aquacadda (Rosas), that from Funtana Raminosa goes abroad for smelting – at present to Boliden in Sweden.

(4) **The copper mine at Calabona, in north-west Sardinia.** This mine is now fast becoming a suburban housing estate for Alghero, but there are many mine buildings around and some of the workers' houses had been made from blocks of heavily mineralised sandstone coloured green due to malachite formation. There is also a disused silo that bears a marked resemblance to the roasting kiln at Rosas and both look very much like 17th-19th century AD British iron-smelting blast furnaces in their construction.

The ore at Calabona is disseminated in a porphyrite intrusion in Mesozoic limestones. The Calabona porphyrite is mainly known for the high-grade copper ore bodies, unfortunately too small, at the contact with adjacent sediments. Production figures are not available, but it has been reported that 9,000 tonnes of high-grade ore (average 9% Cu) were mined in the Salondra district of Calabona between 1911 and 1921 from several lenses. Quite probably a similar amount was mined before and after that period.

A detailed qualitative microscopic study of Calabona mineralization listed over 22 ore minerals of which 15 are copper-bearing. Important ones are chalcopyrite, sphalerite, pyrite, covellite, chalcocite, enargite, luzonite, tetrahedrite, bornite and native gold.[17]

Copper is also present in a cupriferous pyrite ($Fe(Cu)S_3$), with a content of 0.1~1.0% Cu; the presence of at least 30 x 10^6 tons of this mineral is reported. The ore mined came mainly from the secondary enrichment zone: well formed covellite crystals from this zone are exhibited in many museums around the world.

Torpe (near Olbia) has recently yielded some good samples of chalcopyrite but there is no reason to believe these were discovered in antiquity.

(5) **Cassiterite.** One interesting mineral reported from Sardinia is cassiterite.[18] Reference to the geological map showed that it occurred in small amounts on the contact between pegmatites and granite in conjunction with lead and zinc minerals in the Valley of the Leni 10 Km SW of Villacidro and 12 Km south of Gonnosfanadiga at Canale Serci. This area is part of the Iglesiente and shows already that one of the granites in this area is capable of containing tin.

Another important deposit for tin is the vein of Punta di Santa Vittoria on the watershed (about 1200m altitude) between Fluminimaggiore and Gonnosfanadiga. The vein is directed NE-SW and shows an interesting paragenesis. The SW part of the vein has mainly arsenopyrite and, after chalcopyrite, covellite, in a quartz gangue; the NE part of the vein has mainly cassiterite in the same quartz gangue. It is not clear whether there were earlier attempts at exploitation; the last works were before and during the second world war.

In the same area there are several other mineralised, hydrothermal small veins: Perdas de Fogu (Fire rock), Menga, Acqua is Prunas, etc, with a Pb-Zn-Cu paragenesis. Going eastward, toward the granitic intrusions, as is the rule, we find some veins with minerals of high temperature deposition, like Ni-Co.

The smelting of copper ores requires the use of sand or iron ore as a flux. The ores from Calabona would certainly need iron ores to flux them and it is possible that this could be done by using the oxidised pyrite or gossan which would have certainly at the time been present on the surface of the deposit. But there is naturally no scarcity of this ubiquitous element – iron – in Sardinia. It occurs as oolitic type near Canaglie, north of Alghero, as limonite 'nodules' in the limestone near Oliena, as magnetite at Giacurru (Funtana Raminosa) and at S Leone (Cagliari). It undoubtedly has a wide distribution in the island.

The really surprising thing is that there is not more evidence of early slag heaps, whether of iron or copper, on the island. But this has always proved valuable material for road construction and it may underlie some of the remarkably good roads. In the Iglesiente, recent slag heaps from lead smelting (about 60 years old) can be seen in the Fluminimaggiore area.

A good deal of the so-called 'slag' reported on the island is no more than vitrified wood ash which in some cases has come from pottery kilns. However, when some peasants were shown copper smelting slag (in the vicinity of Rosas) near Narcao, in the Iglesiente, they called it 'pietra ferri' and claimed that there was lots of it in their area but they were unable to show us a piece of it. Marcello Serra refers to this as 'un grosso cumulo di scorie, che, sottoposte all' analisi, rivelano un'alta percentuale di ferro (52.83%) ed una traccia molto esigua di rame (0.54%)'.[19] ('a large amount of slag which, upon analysis, shows a high percentage of iron and a very small trace of copper.')

C. Results of Research

(1) Slags

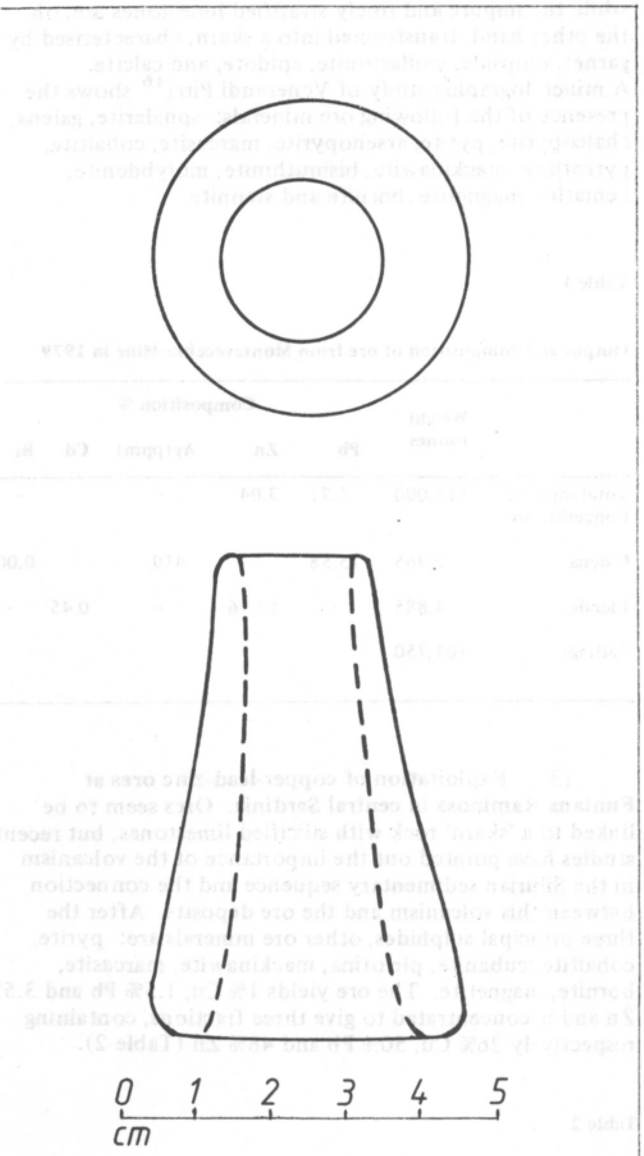
A number of unstratified slags from Cuprifera Sarda at Funtana Raminosa (Gadoni) were obtained from Giandomenico Sini, now Director of the mine at Montevecchio. None of these were typical of copper smelting slag like that in Cyprus. Some came from the area of a large 5m diam structure which may be a 19th-20th century AD roasting furnace. A piece of vitrified granite attested to fairly high temperatures sufficient, at least, to roast ore. Pieces of slag showed silica with metal particles precipitated in a granular and lathy fayalite. While some pieces showed the black glassy type of fayalite slag that one expects from smelting sites, a good deal, although containing copper, was not the normally expected type and was probably connected with the late roasting operation(s).

(2) Evidence for prenuragic metallurgy

The early phase of the so-called nuragic period can be dated to 1500 BC or earlier and can be said to coincide with a well-developed Bronze Age[20]. The metal evidence for an earlier period comes mostly from awls, many examples of which can be seen in the museum collections. It might be mentioned here that a rock-shelter near Grotta Rifugio in the province of Nuoro is yielding shell necklaces consisting of very well drilled disc-type beads 1.5 mm thick x 4 mm OD containing holes of about 1.0 mm diam which can only have been drilled with copper wire loaded with abrasive.[21]

In the earliest metal-using Ozieri culture, copper is very rare but copper daggers and a flat copper axe have been found with Beaker associations (Table 3) between Monte Claro and Bonnannaro contexts.[22]

The rock-cut tombs of Anghelu Ruju (3000-2000 BC) have produced daggers, awls, an arrowhead of Remedello type (2500 BC) with beakers of Almerian type. A rather important artifact which seems to have been overlooked is a tuyere which can be seen in the museum of Cagliari (Fig 1) Tomb XIV-XLV 14-45 30515/270. It has often been the practice in Europe to bury smiths with some of the tools of their trade (the best example is from a grave of the Early Timber Grave culture at Kalinovka near Volgagrad, USSR) and it would seem that this is yet another example of the practice.[23]



1 *Tuyere from Anghelu Ruju.*

SAM I[24] gives some analyses of the square section awls, etc, from Anghelu Ruju (Table 4), where we see that these are mostly coppers with a variable percentage of As, Sb and Ag, which is a fairly typical composition from the EBA. The variability of the As and Sb contents is normal for primitive smelting techniques but the differences in the silver contents either denotes rather different sources or concentrations since one would expect all the silver in a copper ore to be recovered. This material compares very well in composition with the Remedello[25] material from the Italian mainland (Table 5).

Lead is known from the Copper Age when it was used for pottery repairs.[26]

Table 3

Archaeological Periods in Sardinia with dates
(After E Atzeni and G Lilliu[20])

Period	Date BC	Cultural Horizon
Early Neolithic	6000-5500	Cardium - ceramic
Middle Neolithic	4000-	Bonu - Ighinu
Late Neolithic - Chalcolithic	3000-	Oziero - Arzachena - Monte Claro
Bronze Age: Phase I	1800-1500	Nuraghic
Bronze Age: Phase II	1500-1200	
Bronze Age: Phase III	1200-900	
Iron Age: Phase IV	900-500	
Iron Age: Phase V	500-238	

(3) Nuragic period – Late Bronze Age 1500-500 BC

A good deal of material from nuragic or related sites has been previously examined but we do not yet have chemical analyses for more than 11 elements of copper artifacts from excavations.

First, there is the museum material that Junghans and his colleagues analyzed for 11 elements. A good deal of this is of 'Italian' origin and of questionable Sardinian provenance from mainland museums (see Table 6). The bun ingots from Abini (Teti) are of better provenance, and there is also material from Forraxi Nioi (Nuragus), now in Marseilles.[27] More recently, bronze figurines have begun to be analyzed with results discussed below.

Table 4

Analyses of Material from the Anghelu Ruju Tombs
(After SAM 1)[12]

No.	Artifact	Composition %						
		Sn	Pb	As	Sb	Ag	Ni	Bi
556	Dagger	0	0	0.11	0.17	0.01	tr	0
557	Awl	0	0	0.07	0.2	0.01	tr	0
558	Awl	0.01	0	0.02	0.95	1.4	0.01	0
559	Awl	0	0.01	0.3	0.4	0.09	0.01	0.003
560	Awl	tr	tr	0.11	0	0.01	tr	0.01
561	Ring	0	0.34	0.05	tr	0.01	0.02	0.003
562	Awl	0.2	0.3	1.7	0	0.34	tr	0.03
563	Awl	0.05	0.18	1.3	0	0.30	0	0.01
564	Flanged Axe	0	tr	0.78	1.55	0.12	tr	0.25
565	Dagger	0	0.02	0.05	0.76	0.15	0.01	0.009

Table 5

Analyses of Copper Objects of the Remedello Culture of Italy and Sardinia
(After Cambi and Otto and Witter)[25]

Object	Composition %					
	Sn	Pb	As	Sb	Ni	Ag
Dagger	0.0	0.0	7.80	0.0	tr	0.20
Flat axe	0.0	tr	tr	0.0	tr	0.10
Flat axe	0.0	0.3	tr	0.3	0.02	0.10
Flat axe	0.0	0.8	tr	tr	tr	0.05
Axe	0.0	0.09	0.0	0.6	tr	0.05
Axe 0.	0.0	0.07	0.0	0.5	tr	0.05
Flat axe	0.0	0.0	0.15	0.0	tr	0.16
Flat axe	0.0	0.0	0.40	0.0	tr	0.13
Flat axe	0.0	1.2	0.17	tr	tr	0.05
Dagger	tr	0.05	8.00	tr	tr	0.20
Dagger	0.0	0.06	4.60	0.6	tr	0.12

(4) Tin in Sardinia

The plano-convex copper ingots show the normal level of impurities in smelted metal of this period. The tin contents are interesting and show that the ore or the (gossan) flux contain traces of this element. This brings to mind the fact that some of the rocks of the Iglesiente contain this element and that in one case at least it has been found possible to concentrate it to give a cassiterite containing 19.69% tin, with lead.[18]

There is also the possibility of using cassiterite from Punta di Santa Vittoria. This lies on the highest point of Monte Linas (1,236 m) about half way between Gonnosfanadiga and Fluminimaggiore in the northern part of the Iglesiente. The mineralised quartz vein containing the tin mineral (cassiterite) is at present being tested for its economic viability and is therefore a 'prospect' rather than a mine. A piece of quartz containing a mass of black cassiterite crystals was taken for examination. The cassiterite was found to be very pure containing 83.2% Sn which is equivalent to 106% SnO_2 (assuming stoichiometry). This may indicate a small proportion of SnO in the lattice. The impurities are: Si, 0.23; Al, 0.23; Fe, 0.21; K, 0.7%. Calcium was present in some crystals to 0.42% but absent in others (Table 7).

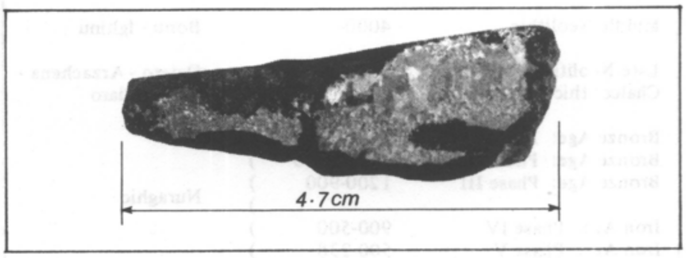
This may be compared with the Cornish mineral found at St Mawgan in Pyder[28] where it can be seen that the main impurities are similar and that traces of Ni, Zn, Au, Ag and Mn are absent. Clearly, with such limited analysis, it would not be possible to distinguish Sardinian tin from Cornish tin; nor, we suspect, any other tin.

Of course, this is not the only source of such material. The gossans of Rio Tinto in Spain contain about 0.2% Sn and if used as ferruginous flux would be capable of giving this sort of addition to the copper.[29] Similar additions have been noticed from Cornwall, Ireland and Saxony. Rarely do we get the large amounts of arsenic we expect from earlier times. In general, then ,the purity of the plano-convex ingots from Abini (Teti), Serra Ilixi (Isili) and Forraxi Nioi (Nuragus) is typical for Late Bronze Age metals.

(5) Nuraghe Genna Maria (Villanovaforru - CA)

Many of the nuraghi give evidence of copper working which is typical of the Late Bronze Age in general. We have examined material from Nuraghe Genna Maria (Villanovaforru), which is being excavated by Enrico Atzeni[31]. One cupriferous piece was a small plano-convex ingot which appeared to be the remains of the contents of a crucible poured into a mould or hollow (Fig 2). It was about 1.5 cm thick. Besides copper, it contained 55.4% lead. It was probably the segregation product from the making of a leaded copper of a type used for making cheap statuary without tin. The composition is given in Table 8.

It is clear that the original copper was of high purity and was not made in the same way as the plano-convex ingots from Abini (ie with tin-containing flux). Low iron is proof of good refining. There is no element that might identify the source and we can definitely say that the added lead did not have the high Ag and Bi contents that Davies[32] says are typical of the Iglesiente and, indeed, typical of that being produced at San Gavino today..



2 *Lead-copper ingot from Villanovaforru.*

Table 6 Composition of nuragic material %

No.	Object	Prov:	Sn	Pb	As	Sb	Ag	Ni	Bi	Au	Zn	Co	Fe
SAM I ∝ II													
544	PC Ingot	Abini	1.8	0.1	0	0	0.04	<0.01	0.01				
545	"	"	0	tr	0	0	0.02	tr	0				
546	"	"	0.25	0.05	0	0.01	0.02	0.02	<0.001				
547	"	"	0.06	0.02	tr	0.05	0.03	tr	tr				
548	"	"	0.16	~ 4	<0.01	0.17	0.25	0.01	0.002		0.04		
549	"	"	0	0	tr	0	0.01	0	0		0		
552	"	"	0.3	0.05	0.02	0.07	0.1	0.2	0.001				
553	"	"	0.7	0.06	0.01	0	0.01	0.25	0.001				
554	"	"	0.14	0.03	tr	tr	0.07	0.04	0.001				
555	"	"	<0.01	0.1	<0.01	0-0.1	0.02	0.04	<0.001				
7938	Ingot	?	tr	0.03	0	0	0.02	0	0		0	0	tr
7939	Ingot	?	0	0.04	1.55	0.18	0.04	0.04	0.02		0	0	0
7941	Ingot	Ilixi	tr	0.29	~0.05	0	0.02	0.02	0		0	0	strong
Cambi	PC Ingot	F. Nioi	0.14	0.986	tr	0	tr	0.099	0	-	0.29	-	0.18
Cambi	PC Ingot	F. Nioi	0.15	0.064	0.15	tr	tr	0.025	tr	-	0.82	-	0.14
SAM I & II													
550	A/H	Abini	0.55	0.09	0.02	tr	0.01	0.02					
551	Point	"	0.01	0.02	1.1	0	0.41	0.03					
7942	Rivet	"	10	0.67	0.83	tr	0.18	0.03	0	0	0	0	tr
7943	"	"	10	0.89	0.08	0	~0.01	0.02	0	0	0	0.07	strong
7944	Dagger	"	9	0.3	0.54	tr	0.03	0.03	0	0	0	0	tr
7945	"	"	5	1	0.68	tr	0.2	0.02	0	0	0	0	tr
7946	"	"	>10	0.08	0.17	tr	0.02	0.01	0.009	tr	0	0	tr
7947	Ingot	"	tr	tr	0.07	0.33	0.14	0.03	0.01	0	0	0	tr
7948	Dagger	"	>10	0.12	0.74	0	<0.01	0.35	0	0	0	0	some
7949	Piece	"	>10	0.03	0.91	0.07	0.05	0.03	tr	0	0	0.01	"
7950	Sheet	"	0.47	0.04	0.3	0.13	0.08	<0.01	tr	0	0	0	strong
7951	Bead	Abini	>10	0.74	0.55	0	0.19	0.03	0	0	0	0	strong
7953	Needle	"	10	0.85	0.56	0.24	0.14	0.05	0.01	0	0.06	0.06	some
7954	Awl	"	10	0.41	0.71	0.09	0.02	0.03	tr	0	0	0	"
7955	Piece	"	6.3	0.07	0.87	0.11	0.05	0.03	0	0	0	0.05	tr
7956	Dagger	"	1.25	0.03	0.09	0	tr	0.02	0	0	0	0	strong
7957	Dagger	"	>10	0.09	0.49	0	tr	0.02	0	0	0	0	tr
7958	Dagger	"	9.1	0.05	0.96	0	~0.01	0.36	0	0	0	0.06	some
7959	Piece	F. Nioi	9.2	>5	0.85	0.24	0.12	0.1	0.033	0	0	0	tr
7960	Axe	"	10	2.6	1.05	0	0.49	0.03	0	0	0	0	strong
7961	Dagger	"	6.7	1.45	0.27	0.54	0.2	0.25	0.011	0	0	0	some
7962	Point	"	10	0.89	0.55	0.19	0.13	0.05	0.012	0	0	0	"
7963	Ingot	"	0	tr	0	tr	0.05	0.04	0	0	0	0	"
7964	Dagger	"	7.5	4.9	0.61	0.3	0.17	0.03	0.02	0	0	0	"
7965	Piece	"	10	2.7	0.45	0.21	0.13	0.05	0.016	0	0	0	"
7966	Prill	"	6.6	>5.0	0.42	0.24	0.19	0.36	0.012	0	0	0	0
7967	Prill	"	7.4	~5.0	0.29	tr	0.08	0.11	0	0	0	0	some

(6) Nuraghe Albucciu, (Arzachena-SS)

Several pieces of metal from this site dated to the 13th century BC were supplied by Ercole Contu and Fulvia Lo Schiavo of the Sassari Museum. The excavator was Professor M L Ferrarese-Ceruti of the Department of Archaeology, University of Cagliari.[33]

Among these pieces was found a piece of heavy grey metal which was certainly not copper-base. It was found to streak paper and had a density of 10.58 g/cc and contained therefore at least 93% lead.

Chemical analysis gave 0.001% Bi and 56 ppm Ag. These were the only two elements sought. Lead isotope analysis by Dr Noel Gale of Oxford gave the following:

$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
2.12097	0.87393	17.893

This isotope analysis matches the galena from Monteponi, Iglesias, but not those from Funtana Raminosa, nor Argentiera della Nurra, Sassari, nor the tetrahedrite from the latter mine.

We can therefore say that it could have come from the Iglesias area but we know that there are deposits in this area that are much higher in both silver and bismuth. It is possible that metal high in silver has been cupelled to recover the silver and give a litharge of low silver content from which this metal has been made.

Another piece, a piece of copper-base alloy sheet, from this site was found to be a typical tin-bronze with 10-12% Sn and 2-5% Pb.

(7) Forraxi Nioi

In 1882 F, Nissardi excavated a hoard of bronze tools and weapons at Forraxi Nioi (Nuragus). The account of the excavation by G Fiorelli describes a crucible filled with tin[34]. Material was selected from two boxes in the store of the Department of Antiquities at Cagliari. The material excavated by F Nissardi in 1882 has been previously examined by Cambi[35] and is labelled 'Nuragus, Forraxi Nioi', 'Oggetti frammentari pronti per la rifondita 17. In 17063'. Box 1 has two compartments: (A) contains typical pieces of tin crusts, scrap bronze or lead. 90% of this is corroded tin and is almost certainly the material mentioned by Cambi as being cassiterite found in a crucible. It contains no tin metal and what metal it does contain is undoubtedly lead which was confirmed by the streak test (lead will mark paper while tin will not). There is no magnetic material in this box, but one bone which is stained green.

The contents of the second compartment (B) seem to be well-corroded bronze. There is one bag containing green, corroded, copper-base sheet which could be fragments of a cauldron or greave. It is all non-magnetic. There are many pieces of bronze scrap which are mostly in the form of plate metal (ie flash cut from the edges of a casting to clean it up as on the case of the chisel or axe from Monte Arrubiu). This is about 2-3mm thick. There is also a piece of rod cast in a two-part mould. A piece of highly mineralised bronze was removed for examination. All this was non-magnetic. But it does contain a small piece of highly magnetic material which could be magnetite or, more likely, cast iron. Recognisable objects included sheet with rivets, spear-butts or the ends of digging sticks, and the hilt-plate of a knife with rivet holes.

Table 7

Composition of Cassiterite from Cornwall and Sardinia - %

	Cornish	Sardinian
Tin	78.7 - 79.7	77.5 - 83.8
SiO_2	0.4 - 1.54	0.3 - 0.5
Al_2O_3	) 0.3 - 1.4	0.43 - 0.44
Fe_2O_3	)	0.27 - 0.40
CaO	0.2 - 0.28	0 - 0.6
TiO_2	0 - 0.07	0 - 0.14
K_2O	-	0.84 - 1.0
Ni, Zn, Au Ag, Mn	) nd	nd

nd = not detected

Table 8

Composition of copper-lead ingot from Nuraghe Genna Maria (Villanovaforru)

Sn	0.01%
Pb	55.4%
As	0.001%
Bi	0.0006%
Co	<0.000% (if any)
Fe	0.01%
P	<0.005% (if any)
Si	0.1%
Mn	<0.001% (if any)
Ni	0.05%
Ag	0.004%
Zn	0.005%
Te	<0.001% (if any)
Al	0.01 - 0.1%
Cu	Remainder (45%)

The second box also had two compartments. (A) This compartment contains pieces of plano-convex copper ingot and a lump of iron with a piece of bronze within it suggesting that it is from the same kind of material as that analyzed by Cooke and Aschenbrenner[36] and the material previously examined from Sa Sedda'e Sos Carros (Oliena)[37]. This is numbered 16749.

Perhaps the most important piece of material in this compartment is a piece of slag – labelled as such – which is not very heavy but glass-like and magnetic in places. It is porous, and judging by the green staining, highly cupriferous. This was removed for further examination. Well over half of the material was pieces of plano-convex copper ingot with a diameter of about 11 cm. The second compartment of this box contains the label 'Ferro oligisto 17076 (16)' and contains various ferruginous items including nails, a 2 cm thick forged slab, a piece like a plano-convex ingot but magnetic, and another piece of slag similar to that in (A). It also contains half an axe-blade which was removed for further examination.

Table 9

Composition of Copper Smelting Slag from Forraxi Nioi - %
Matrix: Silicates and spinel phases

	Euhedral Olivine	Fayalite Lathy Olivine	Intercrystalline glass	Hercynite - Magnetite 'dendrites' (Spinel)
$Si0_2$	30.8	31.4	39.9	0.6
Fe0	57.8	58.3	18.6	75.8*
Ca0	0.4	0.6	17.7	-
Al_20_3	-	0.4	15.5	14.8
Mn0	0.8	0.8	0.3	0.2
$Ti0_2$	0.3	0.3	0.4	1.4
Mg0	8.7	7.9	0.8	1.7
K_20	-	0.1	1.5	-
Na_20	1.1	0.7	0.7	1.6
$S0_2$	-	-	0.4	-
Cu	-	-	-	0.6
Total	99.9	100.5	95.8	96.7

Sulphides and metal components

	Metal	Matte
$Si0_2$	0.6	0.7:0.1
CaO	-	0.4 -
Fe	5.3	12.5:17.8
S	-	24.4:30.6
Cu	98.6	63.8:50.1

- = less than limit of detection (about 0.1%)

* = Calculated as 'Fe0' but trivalent iron is probably present

Table 10

Results of spectrographic analysis of copper ox-hide ingots from Sardinia

	Serra Ilixi			Abini
%	CA1	CA2	CA3	CA4
Sb	0.001	0.001	0.001	0.001
As	0.04	0.04	0.03	0.02
Bi	0.0004	0.0006	0.0002	0.0002
Co	0.005	0.005	0.003	0.002
Fe	>0.02	>0.02	>>0.02	>>0.02
Pb	0.008	0.008	0.005	0.0005
P	~0.005	~0.005	~0.005	~0.005
Si	0.1	0.05	0.2	0.2
Mn	nd	nd	nd	nd
Ni	0.005	0.005	0.003	0.002
Ag	0.001	0.002	0.001	0.002
Sn	0.001	0.001	0.001	0.001
Zn	0.005	0.005	0.01	0.008
Te	0.002	0.002	0.002	0.002
Al	Present in all samples		<0.01 - 0.1%	
Cu	Remainder	Remainder	Remainder	Remainder

nd = <0.001% (if any).

Results of examination

Tin crust from Box 1(A). X-Ray Diffraction (XRD) showed two major constituents, SnO and SnO_2 (cassiterite). Metallographic (thick section) examination showed a two-phase structure with the soft phase (SnO) with a hardness of 178-245 HV forming the majority. This compares very favourably with similar crusts from Cornish tin ingots. [38]

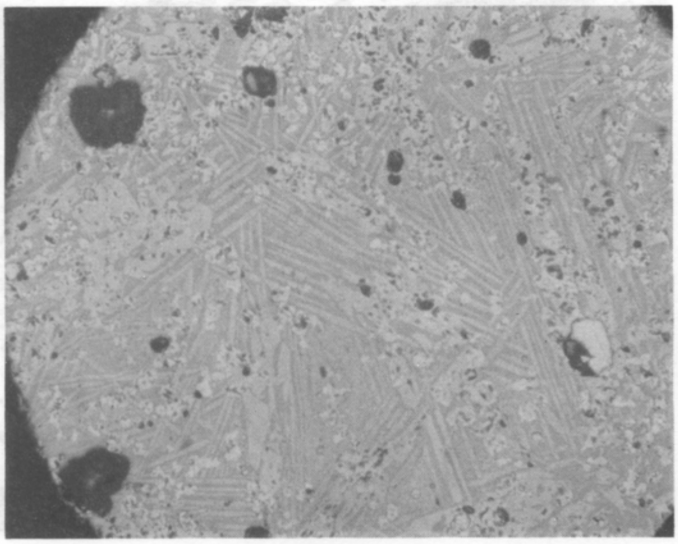
Iron axe blade from Box 2(B). The edge is a low carbon steel with a hardness of 120 HV1 containing ferrite and spheroidal pearlite. The centre (fracture) of the axe blade has a similar composition but has been cooled from a very high temperature to give a widmanstätten structure. The carbon content does not exceed 0.2% and the slag content is low being mainly confined to the centre of the blade. The blade would be a poor one and possibly even worse than a bronze axe-head.

The piece of slag from Box 2(A) weighed 120 g. It was darker and somewhat heavier than the crucible slags or vitrified fuel ash from metallurgical sites which made it of special interest. A microscopic examination showed that it was an iron-containing slag consisting principally of fayalite (ferrous silicate) crystals in a glassy matrix. There were also light equiaxed crystals of wustite (FeO) that were clearly primary, ie the first phase to crystallise out of the liquid. The fayalite crystals often had their familiar lathy habit (Fig 3). This figure also shows a globule of matte (copper-iron sulphide) to the centre right. Fig 4, X 400, shows a group of copper particles in the same fayalite+glass slag. It would appear that the fayalite-to-glass ratio is somewhat lower than the normal smelting slag and that the slag is very heterogeneous suggesting high viscosity, with copper in some places and not in others. The matte globules had a hardness of 170-200 HV which is in agreement with similar phases in other slags. The composition is given in Table 9.

While quite high iron contents are known from crucible slags [39], the size of this piece together with its matte and copper content strongly suggest that this is a badly formed smelting slag. The slag contains insufficient iron flux which has prevented the metal and matte from aggregating properly. Furthermore, the presence of matte shows that the original sulphide ore was not sufficiently roasted and that the smelter had produced a mixed product of copper and matte.

The piece of heavily mineralised bronze from Box 1(B) is a dark green and has a metallic core. The hardness of the green mineralisation is in the range 168-172 HV1 which suggests that its cassiterite content is not very high. It is probably mostly malachite and other oxidised copper compounds together with SnO and varlamoffite (Sn,Fe) $(0.0H)_2$. It is a coarse-grained copper-base solid solution with equiaxed grains but no sign of the alpha-delta phase of the Cu-Sn system. Corrosion has outlined the grain boundaries and deformation markings. The hardness is 92 HV 0.5 ,which suggests that this is a tin bronze with not more than 9% tin or tin equivalent. It contains small amounts of slag and cuprous oxide. This is a bar of bronze which has been well-homogenised (heated) after casting and which was then cold worked probably to give it a round shape. There is no sign of hot working. It is relatively free from lead (less than 1%).

Several authorities (Nissardi and Ramin) have referred to the finding of a 'crucible' at Forraxi Nioi. A crucible is, of course, heated from the outside. The drawing in Fiorelli's report of Nissardi's find makes it clear that this is a furnace not unlike that found in Cyprus [40] in which



3 *Fayalite laths in copper smelting slag from Forraxi Nioi. X100*

the fuel was burnt inside in contact with ore or metal. This furnace is 50 cm diam at the top and 70 cm deep which makes it somewhat bigger than the Cypriote one.

The evidence at Forraxi Nioi would suggest that insufficiently roasted sulphide ores were smelted in a non-slag tapping bowl furnace similar to the type used by Boydell, Ghaznavi and Tylecote [41]. The metal so recovered was alloyed with metallic tin to make a tin bronze. Although it is possible that the tin could have come from Sardinia, it seems on the basis of present knowledge to have come from Spain or Cornwall.

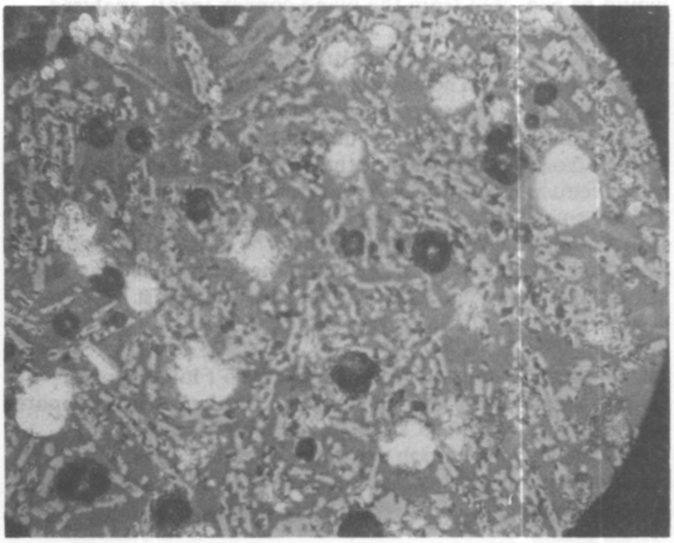
(8) Monte Arrubiu (Sarrok)

One object of interest is an unfinished shouldered bronze hoe from Monte Arrubiu (Sarrok).[42] This is about 20 cm long and still has the 'flash' that arises from metal running between the two halves of a stone mould when these are kept open with shims to allow the air to escape when the metal is poured in. We have recently made such castings of rapiers when examining the problems of casting into stone moulds and this is the first time we have seen such a large amount on a casting in antiquity.[43]

A piece was removed from the 'flash' or excess metal that is present on the edge of this unfinished casting (No 33). Experiments have shown that flash forms on the edge of bronze artifacts cast in two-part stone moulds mainly because of the need to leave a slight gap between the two halves in order to allow the air to escape during casting. At Isleham in England [44] a bronze hoard of the Late Bronze Age has provided a large amount of so-called 'plate' metal which is almost certainly the pieces trimmed from such a casting during finishing. It has been in contact with moulding material on both surfaces and is therefore flat and in good condition and free from corrosion.

It was because the implement from Monte Arrubiu showed what appeared to be such a good example of flash that permission was sought to remove a small piece and compare it with that from Isleham.

Metallographic examination showed that it is a cast tin bronze with a few small areas of the alpha-delta eutectoid which suggests a tin content of about 8%. It contains less than 1% of lead, if any. After casting the metal has been reheated which has resulted in the removal of segregation due to rapid cooling during casting. The structure is coarse grained and equiaxed. There is a small amount of intercrystalline corrosion starting from the surface. The surface is smooth and relatively unattacked and in most respects this piece is very much like the 'plate' metal from Isleham. The hardness is 80 HV which is fairly typical of unworked metal of this period. But the hardness of the cutting edge would be increased by cold work in order to make it a more useful implement.



4 *Copper particles in another area of the same slag. X 400.*

What is interesting in this case is that it has already been homogenised (ie reheated) ready for cold-working the cutting edge in spite of its unfinished state. Clearly it was intended to be finished and not left in its unfinished state as a ritualistic object like some French socketed axes. In this respect it differs from the Isleham material which had been trimmed in the as-cast state.

The Punic-Roman sanctuary of S Andrea Frius has produced a finished example of this type (No 14611) which has a 5 cm wide blade and is 11-12 cm long with a 5 cm long tang.

(9) Material from other sites

One nuragic site (dated to 10th-8th century BC) recently examined and excavated by Dr Fulvia Lo Schiavo is that of Sa Sedda'e Sos Carros at Oliena near Nuoro.[45] This consists of a large settlement on the flanks of a limestone hillside containing the remains of circular huts and enclosures of nuragic type. Prior to excavation, a large amount of bronze was taken from the site – so much in fact that the site was considered to be a 'foundry'. In fact there is no evidence that the metalwork was any more prolific than that on any other European Late Bronze Age site which has had a long period of settlement.

The metal finds comprise a large number of axes, spearheads, spear butts, bracelets, brooches, awls, etc, most of which are fragmentary or showing defects. These give every indication of being a scrap metal hoard, typical of the Late Bronze Age.

This view is reinforced by examination of some of the metal. It was very heterogeneous and some was magnetic showing that it contained some iron. One piece however was clearly a piece of pure copper plano-convex ingot with a high oxygen content and a hardness of 49-69 HV1. This is what would be expected from the plano-convex ingots analysed by Junghans and shown in Table 6. Another piece consisted essentially of two major constituents: copper with slag and a white cast iron. The copper was relatively pure with a hardness of 41 HV and might well have come from a piece of the plano-convex ingot. The cast iron could have been formed from wrought iron if the scrap metal had been heated under reducing conditions or, alternatively, it could be from a badly smelted piece of copper in which some of the iron from the flux had been reduced into the copper. It is now clear that this is a much more common occurrence than was at one time supposed. A third piece was pure cast iron containing only a little copper (Fig 5).

Metal recently reported from the Nuraghe Flumenelongu (near Alghero) has provided a number of plano-convex ingots weighing from 0.266 to 1.625 kg and broken pieces of a shaft hole axe, a trunnion axe and a riveted dagger.[46] Again this is a typical collection of copper-base metal ready for re-casting.

Pieces of ox-hide ingots together with scrap metal have been found at Sa Manda (Sassari Museum). Santa Lulla has produced the ubiquitous stone mauls, pre-nuragic awls and a (D. 15 cm) plano-convex ingot (Nuoro Museum).[47]

Two of the metallurgical items lacking so far from recently excavated Late Bronze Age settlements are moulds and crucibles. However, there are quite a lot of the former amongst museum collections, and many more have been mentioned in the publications of Zervos and Becker.[48] Two examples from the Cagliari Museum are listed:

1) One half of a two-part steatite mould for 2 sickles, a flat object (? axe) and a bill-hook, measuring 30 x 24 x 18 cm. believed to be from Serra Ilixi.[49]

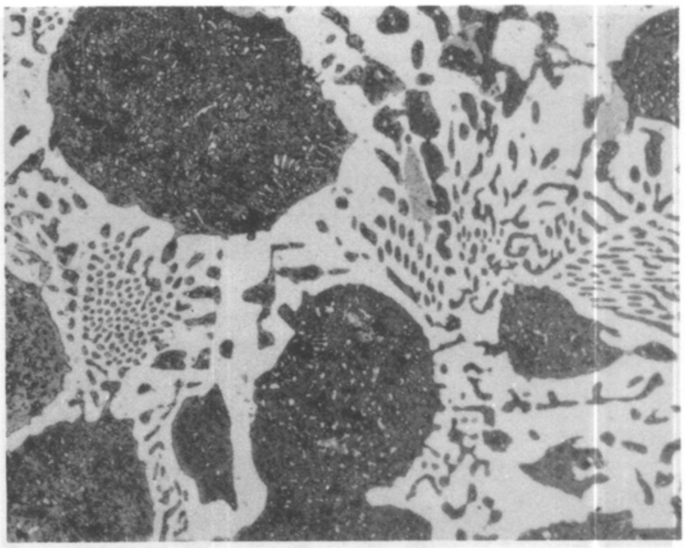
2) A steatite mould from Serra Ilixi with a matrix for 4 bars or axeheads on one side, and for a Danubian axe-adze on the other; 15 x 14.5 cm.[50]

We have even less evidence of crucibles. No obvious examples have been seen but one or two clay vessels not classified as such from Anghelu Ruju may have been used as crucibles. There is also a (?) lamp from Serri in the Museum at Cagliari which looks very much like a boat-shaped crucible. A small flat-bottomed pot from Abini which is c 11 cm high x 10 cm diam with a 5 cm diam base may well be a crucible, but if so such a type is hitherto unknown in a Late Bronze Age context. More likely is an object from Nuraghe Losa which looks like a crude boat-shaped crucible. Clearly, the structure at Forraxi Nioi, beside which 10 kg of oxidised tin was found in a Late Bronze Age level, was not the remains of a crucible but a furnace in which a crucible could have been placed.

Crucibles of this period in Western Europe are few but a hemispherical type with a side-pouring handle is common in the Eastern Mediterranean.

There is a better (?) crucible from the **'Deposito Sacro'** of Santadi in the Grotta Pirosu. This is hemispherical with an ash deposit on the underside (Cagliari Museum No 53351) but there are other similar pottery bowls without ash but with handles.

Perhaps the most important objects in the museum at Cagliari are the so-called 'Cypro-Minoan' ox-hide shaped copper ingots. Sardinia becomes the most westerly provenance of a type that is found in the Central and Eastern Mediterranean. They have been known in Sardinia for well over a century and there are at least twelve findspots for whole or cut-up ingots.[51] The Museum contains three whole ingots and some pieces broken off them. The results of the analyses of the three whole ones and the 'leg' of one from Abini (Teti) are given in Table 10.[52]



5 *Cast iron in a mixed scrap metal from Sa Sedda. X 400.*

Comparison between the compositions given here and those in Table 6 shows a big reduction in the tin content and the other elements. In fact the ox-hide ingots are a good deal purer with the possible exception of iron. They certainly reflect either improvement in smelting and refining techniques or in the purity of the ores used. We would very much doubt whether the two lots could have come from the same ore source. On the other hand, if we ignore the added lead, the purity is far closer to that found in the piece from Nuraghe Genna Maria (Villanovaforru). There are many analyses of the ox-hide ingots, and it is clear that the Sardinian examples agree well with the majority from sites in the Central and Eastern Mediterranean.

There are a number of analyses of the popular Sardinian figurines (**bronzetti**), but unfortunately most of those analyzed have no specific provenance (see Table 11). These are all tin-bronzes with relatively little lead for the period.[53] The iron content is higher than the plano-convex ingot material which may be due to contamination with iron tools, if made during a transition period between the Late Bronze Age and the Iron Age. More of these have recently been analyzed by J Riederer[54] and confirm the variable iron contents.

It seems that the Late Bronze Age metallurgy in Sardinia resembles the same period in SE England where many scrap metal hoards have been found containing plano-convex ingots of pure copper brought in from other parts of the British Isles or from abroad.

(10) Iron Age and Roman metallurgy

The 'fusoria' on the Punic-Roman site at Nora is very interesting as it has been heated to a much higher temperature than the lower-than-800° at Nuraghe Ortu Comidu (Sardara).[55] The plan resembles Roman period and later lime kilns which had to be run at a temperature of 950°C to calcine limestone for building purposes. There is much reddening of the structure but it could not be used for smelting any metal as the wind/withdrawal aperture is too long and narrow for withdrawing slag and metal. It could however have been used as a roasting furnace, although it is difficult to imagine such a smelly process being carried out in a habitation site when the mountains are close behind.

The most prolific material from this period is the lead anchor stocks in both the Cagliari and Sassari Museums. As these may have been made anywhere in the Mediterranean there is little point in doing analytical work to see if they come from Sardinia itself.

In the Museum at Sassari are a large number of artifacts from what is believed to be a Roman wreck from Capo Bellavista which is about halfway down the east coast of the Island. Amongst this material were a number of iron bars (blooms) of the 'stumpfbarren' type, by-pyramidal and about 25 cm long and 5 cm square at the ends. They were slightly larger, perhaps 7 cm square, at the centre but were unusually 'stumpy'. There were also 7 lead ingots of the normal Spanish type and two of these had Spanish type inscriptions, with E D CERDO on the ends and DAGUTIUS GF on the convex surfaces. These are dated to 30 BC - 10 AD. Another fifteen similar ingots came from Capo Falcone and these had inscriptions on the ends.

Table 11

Composition of Sardinian Bronzes (Small Statuettes). %

Cat/Reg	Cu	Pb	Sn	Ag	Fe	Sb	Ni	Co	As	Au	Bi	Zn
British Museum												
Cat 338	88.0	1.00	10.0	.025	.040	(tr)	.033	.033	.0550			
Cat 337	94.0	0.400	5.0	.070	.420	.250	.035		100			.200
1914.3-18.1	89.0	.070	10.8	.020	.070		.050	.020	.200		tr	
1926.5-11.4	86.0	.750	14.0	.065	.140		.055	005	.150			
1926.5-11.6	88.0	1.30	8.70	.050	.800	.025	035	035	.120		.003	.030
1926.5-11.13	89.0	.600	10.8	.080	.170	.050	.020	.010	.300		.007	.080
1926.5-11.14	89.0	.570	11.4	.080	.170	.050	.170	.020	.250		.003	
1926.5-11.11A	89.0	.220	9.40	.006	.050	.030	.030	.005	.070		.004	.007
1926.5-11.11B	90.0	.270	9.60	.004	.040	.040	.040	.007	.010		.003	.005
1926.5-11.2	92.0	.280	7.60	.120	.140	.040	.020	.015	.220		.005	.008
1926.5-11.16	91.5	.500	6.80	.070	.290	.020	.020	.020	.450		.002	.025
1926.5-11.12	90.0	.320	9.10	.040	.038	.025	030	.025	.400	.002	.003	.025
1926-5.11.15	87.5	1.15	9.30	.125	590	.025	.025	025	400		.003	.025
1926.5-11.138	97.0	.500	2 20	.090	.220	.040	.025	025	.300		.004	.010
1926.5-11.138	93.0	.390	4.30	.200	.840	.030	.025	020	.170		.007	.035
1926.5-11.22	82.5	600	16.3	.110	.070	.050	.030	.025	300		.003	
1926.5-11.41	90.0	.460	9.10	.120	.045	080	.020	.015	.370		.005	.005
1926.5-11.113	91.5	2.50	6.40	.110	.110	.030	.030	.020	.430		.005	.020
Cat.429	88.5	.450	9.80	.070	.110	.250	.120	.008	.100		.008	.030
Cat.430	88.5	.380	11.8	.017	.090		.014	.008	010		.004	.030
1926.5-11.1	89.0	.120	9.60	.300	.150	.020	.040	.030	.300		.003	
1926.5-11.8	89.0	1.10	9.30	.240	.150	.020	.040	.015	.200			
Albright-Knox Buffalo	88.5	<.45	5.7	.03	.37	<.06	<.10	.02	.44		<.003	.25
R.I.S.D. Providence	93.8	2 5	7.0	.03	.03	.13	<.11	<.002	.53		<.003	<.30
D.I.A. Detroit	78.9	<.60	7.7	.03	.27	< 04	<.07	.023	.61		<.003	<.20
Fogg Cambridge	82 6	<.47	7.5	.03	.24	<.06	<.14	.05	.58		<.003	.33
Cleveland	81.6	<.63	8.0	.03	.36	<.05	<.12	.02	.36		<.003	.34

The last five have been published by L Stodulski [53]

The estimated accuracy is of the order of ± 20% except for the copper and tin where it is about ± 1%.

In the Museo Archeologico Nazionale at Cagliari are lead stone clamps of the familiar 'I' section which probably belong to the Classical Greek period.

The most important items from the Capo Bellavista wreck are the purse-shaped tin ingots which strongly resemble the purse-shaped ingots from Port Vendres near the Franco-Spanish border[56]. As there was some doubt in the minds of the museum authorities as to whether these ingots were really made of tin we were asked to remove a small piece from one of them for examination. The operation of cutting left us in no doubt that this was tin. Tin is harder than lead but is soft enough to cut with a pair of pincers and the metal was more of a creamy white than the greyer colour of lead. The cut surface did **not** mark paper which lead will do. Metallurgical examination showed that it was indeed tin and had a hardness in the range 5.6 - 6.9 HV1 which compares with the hardness of pure cast tin of 5.0 HV given by Tabor[57].

The ingots varied considerably in size and weight. Some were double, ie they consisted basically of two ingots or rectangular blocks 5 cm thick x 6 x 12 cm side, fastened together by a complex web forming the handle. These weighed no more than 3.5 kg. Then there were single rectangular ingots again 5 cm thick by 18 by 14 cm side with a handle which weighed about 10 kg. Clearly these varied in much the same way as those found by Colls **et al** which weighed from 3 to 9 kg.[58] The rectangular ingots from Haifa weigh 11.4 and 11.9 kg respectively but have no purse-like handles.[59]

Otherwise the metallic material for this period is not great. Smithing slag has been found in (?) Punic levels at Ortu Comidu, but most of the 'slag' reported from other sites has turned out to be no more than vitrified fuel ash.

One object that might belong to this period rather than the Bronze Age is a trilobate bronze arrowhead (from Nuraghe Cuccuru Nuraxi (Settimo San Pietro) in the Museo Nazionale at Cagliari), of the type for which a mould was found at Mosul (Iraq) and reported on by Maryon.[60]

(11) Post-medieval metallurgy

At the Speleological Museum at Nuoro is a collection of counterfeiter's materials dating to the Savoyan period (1770 AD) and found at Ignota (Orune). This has produced the best crucible yet found on the Island, a very small, handled crucible of clay capable of making one coin, together with a two-part clay mould vertically poured.

(12) More recent metallurgy in Sardinia

As Davies[61] has pointed out, the Iglesiente has been worked for lead from Roman times, if not earlier, up to the present time. Evidence exists today in the mine at Montevecchio and the smelter at San Gavino. Modern plants have been set up on the coast, for example, the lead-zinc smelter Portovesme which supplies lead to San Gavino for refining The lead being smelted at San Gavino still contains more than the world average silver values, and 0.6% bismuth; these elements dictate the electrolytic refining route. Considerable silver (and gold) is being recovered.

Two copper mines are being worked and have been worked in the immediate past. The first of these at Monte Rosas has a new shaft at Aquacadda. The old smelter is shut down and all the chalcopyrite now goes to Huelva (Spain) for smelting. But there are some remains of the old smelter plant such as the calcining kiln which looks rather like an old stone iron blast furnace. There is also an inclined flue going up the hillside and terminating in a chimney at the top. This was probably connected with a roaster.

At Funtana Raminosa there are signs around the mine of earlier working. Where adits surface there are traces of green copper minerals in the rocks rather like those at Alderley Edge in Britain. There was little evidence that could be earlier than the 19th century: a large roaster similar to one seen in Iran[62]; and an open-cut mine on the top of the hill above the present mine where fire-setting seems to have been used. There is plenty of gossan which, to those who have not seen it, can be confused with early smelting slag since it is high in iron and has a mammilated appearance.

D. Discussion

The general impression one gets of early Sardinian metallurgy is that of a well--developed Late Bronze Age casting technology after a prenuragic Copper Age.

Taking the evidence of the contents of the tombs at Anghelu Ruju (Table 3) we see that the material used was an impure copper, occasionally moderately high in arsenic and bearing a strong resemblance to the metal used in the Remedello culture of the mainland. This metal is low in tin and low enough generally in arsenic to have come from a deposit such as that at Funtana Raminosa, but it must be reiterated that there is no evidence at all that it came from there.

When we come to the Late Bronze Age material from Abini, Forraxi Nioi and Serra Ilixi we see in the ingot material two groups:

(a) One with a perceptible and significant tin content that is unusual in the Late Bronze Age but which could have come from a tin-contaminated deposit that could exist in the Iglesiente and another,

(b) Shown in the ox-hide ingot metal from Serra Ilixi which is purer and is typical of metal from the Eastern Mediterranean.

Ingots of the latter composition occur in all three sites but the bulk of the metal from Abini is of the first type. It is worth noting, however, that the tin-contaminated material is not confined to Sardinia but occurs in many areas of the Mediterranean and the Near East but in an earlier context than it does in Sardinia.

Recent work shows that of the different sites at which fragments of ox-hide ingots were found, many of them were in the mountainous province of Nuoro. It becomes even clearer that this type was much in use in the Late Bronze Age in Sardinia but there is still no evidence for its production in the Island.

Our earlier report has discussed the problem of the ox-hide ingots and the question of their origin. Since then we have the report of Zwicker[63] and his colleagues who find that the trace elements in the two types of ingots, the broad and the narrow, are similar, although the distribution between ingot and slag is different. In the broad ingots cobalt is in the slag while in the narrow ones it is in the matte (a mixture of metal sulphides). They suggest that the broad ingots were earlier and imported, while the narrow ones were later and made from matte-smelted local ores such as those from Funtana Raminosa. Cobalt had also been singled out by Wheeler, Maddin and Muhly as a determinant of source, but this idea has since been modified.[64] Unfortunately, the trace element pattern in the Funtana Raminosa mineral is similar to that in the Cypriote ores, so no clear distinction can be made of the original source of the ores.

Further work by F Lo Schiavo and M Sanges at Sa Sedda's Sos Carros and S Lulla has produced more stone moulds, plano-convex ingots and what appear to be ladle-like crucibles, all adding to the evidence for a very general and intensive metallurgical tradition.[65]

The absence of well-defined crucibles is a problem in trying to produce firmer evidence for a metal-working industry, but otherwise the nuragic sites demonstrate the widespread nature of the normal casting processes that one would expect in a well-developed Late Bronze Age community. The stone moulds indicate this, and the ingot and scrap-metal support it.

Most of the results of the examinations described in this report speak for themselves. The most important conclusion arises from the slag from Forraxi Nioi. If this slag is correctly stratified, and there is no reason to doubt it, it represents the first piece of evidence for nuragic period copper smelting on the island. It would be more satisfying to know whether this piece represents one piece from a considerable amount of similar material or whether it is an isolated experiment. Its shape suggests that it is a piece of a larger amount, but it certainly represents an early primitive stage in which the necessity of adding sufficient iron was not understood. Perhaps more of this material lies under the roads of the island?

The cassiterite, or more correctly the lower oxide of tin (SnO), was said by Cambi to total 10 kg and was found together in a Late Bronze Age level with a slagged crucible and grains of incompletely reduced cassiterite. The 10 kg was in the form of pieces of 1 to 3 cm. It is now quite clear that this is the material examined and that it represents pieces of oxidised and broken tin ingot, and is corroded man-made material and not natural cassiterite mineral. Most likely it has been brought to the site to make bronze by the melting of tin and, perhaps, locally smelted copper, in the furnace described by Fiorelli in 1882.[66]

The evidence of the piece of slag is indisputable. The next steps in this direction of research is to seek out more examples of copper and other smelting slags. In addition, a program should be set up to provide quantitative trace element analyses of the presently mined ores, accompanied by the identification and study of crucibles.

E. Conclusions

The overall picture of nuragic Sardinia is one of a well-developed Bronze Age copper and lead technology. It is possible that at first the necessary copper was imported from the Aegean in the form of plano-convex and, later, ox-hide ingots and that this was adequate to supply the casting and working side of the industry. Later, however, by the twelfth century BC, copper was being supplied from local ores.

Some kind of contact with Mycenaeans before 1200 and the presence of Phoenicians, now dated as early as the eleventh century, are evidence of prospecting and/or trading.[67] The available evidence certainly does not contradict the possibility that both lead and tin could have been produced from indigenous ores. The suggestion has been made that, after 1200, there was an increase in population and that nuragic leaders were becoming prosperous because of the metal trade. If Sardinia enjoyed the position of an emporium, there is still the problem of identifying the presence of Sardinian material outside the island.

It would appear that by the Roman period copper imports return, as it was found that the local ores were difficult to work and there was more easily available ore in Spain and Cyprus. But lead probably continued to be worked. By the 19th century AD, working of lead and copper ores was resumed until at the present time production from local ores, or lead, zinc and copper is the highest in Italy.

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The analytical work was done by the BNF Metals Technology Centre at Wantage, UK: by Dr P T Craddock of the British Museum Research Laboratory: Geomet Services Ltd., Chessington, Surrey, and by R E Clough of the Institute of Archaeology, London. We are particularly indebted to Dr Craddock for allowing us to use the British Museum data which will be incorporated in 'Composition of Copper alloys in the Classical World (Part 4),' **JAS** (forthcoming).

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Appendix: The smelting of copper ore from Calabona

J F Merkel and R F Tylecote

Enough of the Calabona No 2 ore was collected for a smelt. This ore was green in colour – showing that at least a thin superficial layer had been converted to the basic carbonate, malachite. But X-ray diffraction showed that the principal compounds were: quartz, calcite, tenorite and cuprite.

Thermogravimetric analysis of a 350 g sample in air confirmed the presence of some malachite by the decomposition at low temperatures (Fig A). There was also a small amount of sulphide, and the lime was clearly present as the carbonate undergoing decomposition at above 800°C.

The full analysis of the ore is given in Table A. The copper content is high and, together with the lime and iron, the ore is virtually self-fluxing, if we can forget the additional lime that would be added to the slag as fuel ash. This requires the addition of an iron flux to reduce the lime content of the slag which otherwise would be too viscous at 1200°C.

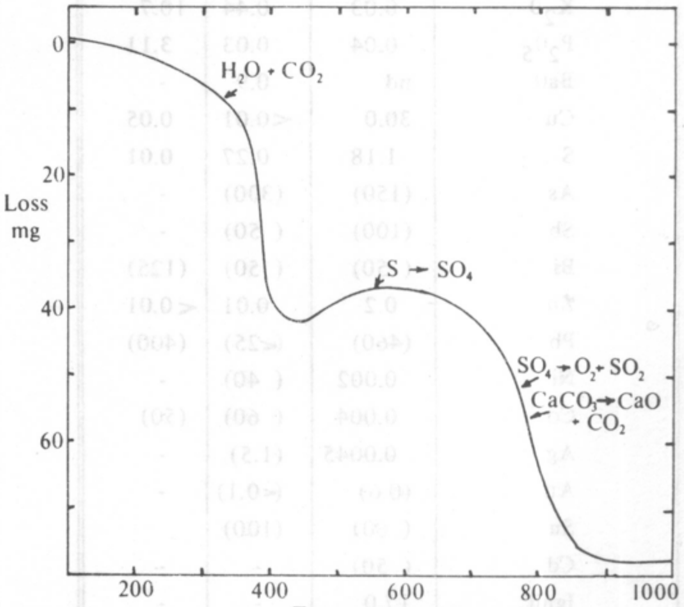

Fig A

Smelting

Smelting was carried out in a large shaft furnace operating with three tuyeres. It was an enhanced design of the Type A furnace used by Boydell in 1978. Details will be forthcoming in a publication of the Institute of Archaeo-Metallurgical Studies.

Products

Most of the slag was tapped, less than half stayed in the furnace forming a plano-convex ingot of slag above the liquated copper, which was concentrated below each tuyere. The slag, metal, and the flue dust which was gathered from around the furnace after the experiment, were analysed with the results shown in Table A. In spite of the large amount of hematite flux added, the lime content is still high in the tapped slag, which explains the relatively high viscosity.

The metal analysed was relatively high in iron; it had an iron content of 9%. Much of the product had an even higher iron content as was found in the earlier work on copper smelting. The composition is what was expected on the basis of previous experience Sulphur and arsenic are the main impurities. The arsenic has come from all inputs. The zinc in the ore has been lost as fume. The nickel has come from the thermocouples inserted from time to time for internal furnace temperature measurements.

The iron and sulphur should be removed by careful refining with an air blast during remelting. This would mean that the chief impurities would be As, Sb, Pb, Zn and Sn in quantities varying from 600 to 100 ppm. Presently, copper metal from the Calabona ore is indistinguishable from many other coppers available in the Mediterranean from the Chalcolithic to Modern Times.

Acknowledgements

This smelting experiment was number 21 in a series reconstructing Late Bronze-Early Iron Age copper smelting at Timna, Israel. It was funded by the Institute of Archaeo-Metallurgical Studies.

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Table A Inputs and Products for Calabona Smelt

%	Input			Product		
	Ore	Flux	Charcoal ash	Flue dust	Tap slag	Metal
Fe	-	-	-	-	-	9.00
Fe_2O_3	21.6	65.40	1.80	26.6	22.3	-
FeO	5.0	0.64	<0.1	7.3	23.1	-
SiO_2	12.9	17.6	5.01	25.3	32.3	-
CaO	16.5	6.05	44 . 1	18.9	14.8	-
Al_2O_3	0.38	0.89	0.79	1.18	1.54	-
MgO	0.90	0.57	4.56	1.83	1.16	-
MnO	0.72	0.09	0.49	0.31	0.23	-
TiO_2	<0.01	0.11	0.21	0.16	0.38	-
Na_2O	0.05	0.30	0.59	0.32	0.24	-
K_2O	0.03	0.44	10.7	1.61	1.16	-
P_2O_5	0.04	0.03	3.11	0.05	0.19	-
BaO	nd	0.9	-	0.9	0.60	-
Cu	30.0	<0.01	0.05	2.48	0.33	89.1
S	1.18	0.27	0.01	-	0.02	0.98
As	(150)	(300)	-	(250)	(50)	(600)
Sb	(100)	(50)	-	(50)	(50)	(350)
Bi	(50)	(50)	(125)	(75)	nd	
Zn	0.2	0.01	<0.01	0.10	<0.01	(200)
Pb	(460)	(<25)	(400)	(100)	(25)	(300)
Ni	0.002	(40)	-	(60)	(50)	0.3
Co	0.004	(60)	(50)	(60)	(40)	(50)
Ag	0.0045	(1.5)	-	(6)	(1.2)	(87)
Au	(0.6)	(<0.1)	-	(1.2)	(0.1)	(1.1)
Sn	(60)	(100)		(180)	(60)	(100)
Cd	(50)	-	-	-	-	-
Ignit. loss	17.0	-	-	-	-	-

nd = not detected (= ppm)
Ash content of charcoal = 4.3%
H_2O content of charcoal = 8.7%

Spinning, Turning, Polishing

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Research Laboratory, British Museum

Since the invention of the lathe, turning has been the obvious way to finish circular vessels which were shaped by raising or casting. The centering pip (Plate 1) and annular scratches on the vessels are the familiar evidence of this work. Using the primitive pole lathe with its low power and intermittent action only finishing work was possible. However, when the principle of the crank was fully understood and applied to drive a continuous action lathe the more fundamental shaping processes of deep carving and of spinning could be contemplated. It is the purpose of this note to clarify the surviving evidence of these two latter techniques with reference to specific examples recently examined in the British Museum Research Laboratory. For the purpose of this paper turning is taken as the removal of metal with a chisel generally, whereas carving is restricted to the removal of metal in the production of an annular pattern.

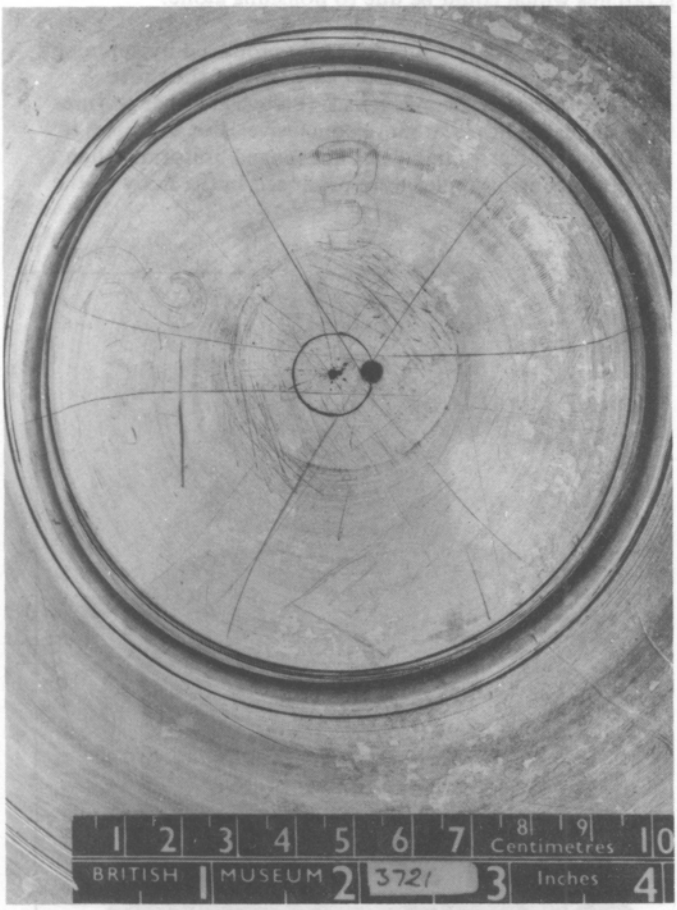

Plate 1 *Base of large silver bessel (P R B Reg 1975 10-2 2.7), from the Water Newton Treasure showing very prominent annular tool chatter and at least two centering pips.*

A. Turning and Carving

Turning was extensively used to thin down castings and to remove surface irregularities from raised or spun vessels. The chisel often did not plane the metal continuously but in a series of very short interrupted cuts, which produced the highly characteristic annular chatter marks on the workpiece (Plate 1). Although easily removed by polishing the chatter marks are surprisingly common on Late Antique plate. Turning of soft metals such as pewter or silver and very light carving[1] was easily within the capability of a pole lathe. However, it has been claimed that the deep concentric rings found on the base of many Roman bronze and brass vessels were also carved on the lathe (Plate 2). In particular Mutz[2] has attempted to emulate this supposed Roman practise of deep carving using a lathe of his own devising. He found it impossible to carve the deep grooves without a crank-operated continuous lathe, for which there is no evidence before the medieval period. However, the real problem seemed to be whether the bases really were carved as assumed by Mutz or whether they were cast. The presence of a centering pip and concentric scratches on the vessels is the only evidence of turning but this could as easily have resulted from cleaning up and polishing. On all the many examples of these deep grooved vessels examined by us there was no evidence of tool chatter. In fact none of the grooves showed any mistakes or miscuts or any evidence of the use of a chisel that one could have expected. In fact, we doubted whether the grooves had been carved at all[3].

Plate 2 *Decorated base of bronze bowl part of the Ribchester Hoard (P R B Reg Ribchester 4).*

However, this was negative evidence, perhaps the craftsmen engaged in this carving were much more skilful or consciencious than their fellow craftsmen. In order to obtain positive proof that the grooves were cut rather than cast it was necessary to cut a V section extending from the edge to the centre from one of the bases for metallographic examination. If these grooves had been carved into the metal then some distortion of the metallographic structure would be inevitable. The removal of such a section would cause considerable damage to the object, and our interest in resolving the question had to wait until we were asked to examine the hoard of Roman metalwork from Ribchester, Lancashire now in the Department of Prehistoric and Romano-British Antiquities of the British Museum (to be published by the authors with R Jackson). The hoard includes a fragmentary patera (Ribchester 4) with a typical heavily grooved base (Plate 2). The metal was analysed by Atomic Absorption spectrometry and found to contain:

Cu	Sn	Pb	Fe	Ag	Ni	Zn	Sb %
75.5	14.7	10.5	0.23	0.055	0.04	0.05	0.01

A section was cut to the centre through relatively uncorroded areas where the surface survived in pristine condition (Plate 3). All areas of the section were examined polished and etched with ferric chloride, and no evidence of working was visible even in areas immediately beneath major changes in profile where working if employed would be heaviest (Plate 4). The globules seen in the sections are of lead, and it seems inconceivable that these could have escaped some deformation during heavy working. These results are conclusive evidence that the base of this vessel which can be regarded as typical is a casting, and that there is no evidence for deep carving being practised by the Romans.

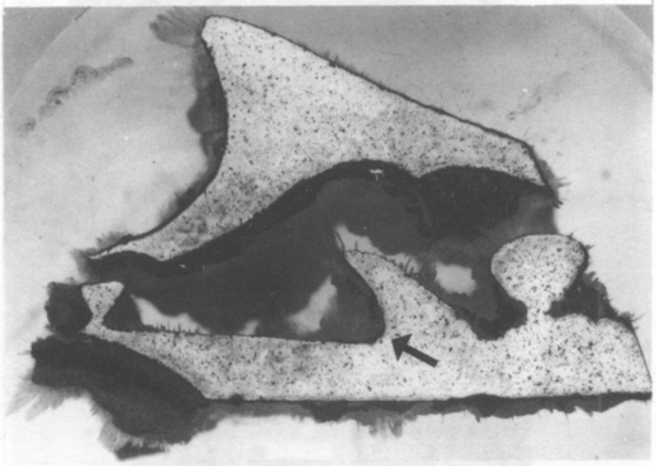

Plate 3 *Two pieces of the section through the decorated bowl Ribchester 4. The position of metallographic section, Plate 4 is indicated by an arrow.*

B. Spinning

We must now move forward a thousand years to consider the evidence for spinning. Here, a disc of metal is spun on the lathe and pushed or burnished with a metal tool against a wooden former to shape the metal. The method is quick but does require a powerful continuous action lathe. Maryon[4] claimed that he detected spinning on Late Hellenistic and Roman plate but his evidence seems only to have been the now familiar centering pip and annular scratches which could be due to polishing alone.

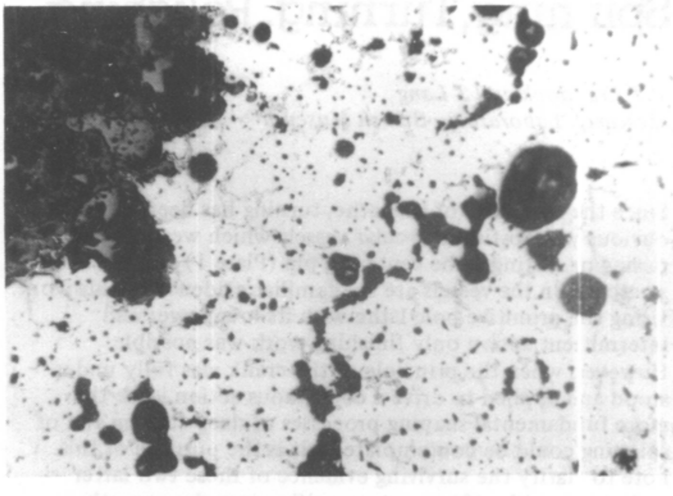

Plate 4 *Typical metallographic section showing no distortion of the structure. The black areas are globules of lead.*

Certain shapes are much more easily produced by spinning than by raising and this is especially true of the short angular profiles of Islamic vessels (Plate 5). Other features than shape are however more conclusive. For example, if the tool used for spinning was not moved uniformly then broad concentric ripples were produced in the body of the

Plate 5 *Heavily inlaid brass Syro-Egyptian Candlestick of about 1300 AD OA Reg 66 12 29 62 formed by spinning.*

workpiece and comparable ripples could not be produced by hammering. Usually the ripples were removed from visible outside surfaces by turning but they are often preserved on the inside. The Islamic candlestick dating from about 1300AD shown in Plate 5, is now in the Department of Oriental Antiquities (OA Reg 66 12-29 62) displays these ripples clearly on its underside (Plate 6). The candlestick is of brass and analysis by Atomic Absorption Spectrometry showed it to contain:

Cu	Zn	Pb	Sn	Ag	Fe	Sb	Ni	As	Bi %
85.5	10.8	1.1	0.9	0.05	0.18	0.3	0.02	0.7	0.002

Mn, Cd, Au and Co not detected.

The base has been spun and then hammered on the edge to thicken the rim. The stem and top were spun separately and soldered to the base.

The distinctive profiles and ripples characteristic of spinning have not been observed on vessels dating to before Medieval times. The origins of spinning as a metalworking technique has not attracted much attention previously, but this typical Islamic piece and its fellows may well represent its earliest use. The reason for the relatively late appearance of the technique may well have been the lack of a suitable lathe. The origin of the continuous action cranked lathe is likewise uncertain but there is no firm evidence before the medieval period.

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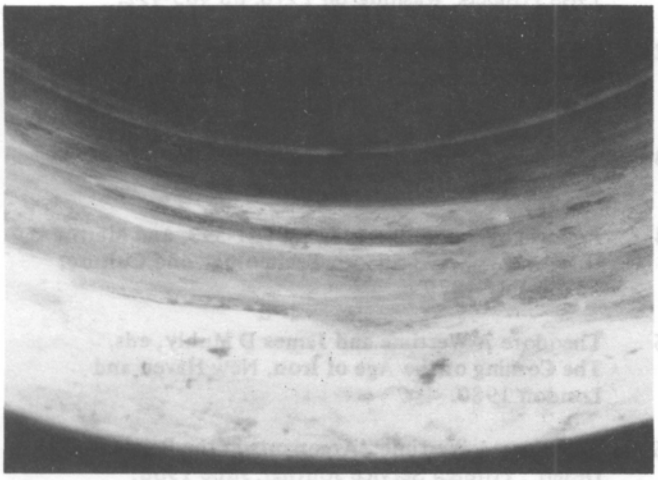

Plate 6 *Oblique view of interior side of the candlestick showing concentric ripples diagnostic of spinning.*

Obituary

Theodore A Wertime 1919-1982

Theodore A Wertime, historian of metallurgy and member of this Society, died 8 April 1982 in Chambersburg Pennsylvania after a long illness. He was 62. His widow, Bernice, known as Peggy, has since removed to 709 Cumberland Avenue, Chambersburg Pennsylvania 17201. They had four sons. The eldest, John T Wertime, served as interpreter on the National Geographic Society – Smithsonian Pyrotechnical Reconnaissance of Afghanistan, Iran and Turkey[1] which Ted organized in 1968 and which among others included HMS members Robert Brill, Frederick Matson, Radomir Pleiner, Beno Rothenberg, and Ronald Tylecote. Another son, Steven F Wertime, was editor with his father of the proceedings of the symposium on Early Pyrotechnology held in Washington in 1979[2].

After graduation from Haverford College he served in China during World War II with the Office of Strategic Services, then at the war's end joined the State Department. He served as cultural officer in Iran and in Greece, edited the Voice of America's 'Forum' and was the US Information Agency's energy program officer. He retired from the Foreign Service in 1975 and joined the Smithsonian Institution as a research associate in the Anthropology Department, and was visiting scientist at the University of Pennsylvania and the University of Minnesota.

He earned an MA in history from American University and during his foreign service career embarked on the research which, with much encouragement from Cyril Stanley Smith, led to his first book, *The Coming of the Age of Steel*, published in 1962[3]. Later Ted was to organize a symposium on *'Metals in History'*[4] in honour of Cyril Smith, and to bring about the festschrift celebrating Cyril Smith's 75th birthday, which became *The Coming of the Age of Iron*, edited with James D Muhly[5]. Professor Smith was one of the speakers at the memorial service for Ted held at the Smithsonian on 26 June 1982, and in his remarks recalled Ted's penetrating insight into the origins of iron smelting. It occurred during the 1966 expedition into the Iranian desert[6]. They were visiting a traditional Persian lead smeltry, and at this furnace there was also a discarded iron bear of enormous size. It was this bear that led Ted to identify the beginnings of iron metallurgy in the waste products of lead and copper smelting.

This expedition was not Ted's first. He had made two previous to 1966 into the Iranian desert, and on one had smelted lead in an assay furnace and he had written subsequently on *'Man's First Encounters with Metallurgy'*[7]. In 1970 and 1971 he made two excursions, one with Constantinos Conophagos and the other with Ahmet Coskun, on 'The Metallurgical Trail of Homer and Strabo in Northern Turkey'[8]. He discovered black sands 28

kilometers west of Ordu on the Black Sea which contained more than 70% magnetite, but failed to find a source of tin. His interest in the source of the tin in ancient bronze inspired another expedition in December 1976 with James Muhly and George Rapp to the Eastern Desert in Egypt, where four cassiterite mines were located, one containing eight inscriptions dating to Pepi II[9], and also to organize a symposium at the Smithsonian in 1977 on *'The Search for Ancient Tin'*[10].

Ted was not persuaded by the arguments of Colin Renfrew and others to accept the independent invention of metallurgy in Europe, and in 1973 he mounted an expedition which included Ronald Tylecote, James Muhly, George Rapp, Alan McPherron and Vincent Pigott and which examined the evidence at Rudna Glava as well as on Kea, Cyprus and at Alaca Huyuk.[11] Ted Wertime saw the beginnings of metallurgy as one part of a whole technological art he chose to call pyrotechnology [12,13] and which was the subject of a symposium he organized at the Smithsonian in 1979[2]. Implicit in pyrotechnology is the prodigious use of fuel, and in 1978 Ted organized yet another symposium, this one on deforestation. His final expedition was undertaken in November 1980 to Lavrion and to archaeological and mining sites in Cyprus to locate ancient cements, especially those found in ancient cisterns and elsewhere having good hydraulic properties. Upon his return he organized a symposium on ancient Technology at the American Anthropological Association meeting in December 1980, and at his death was in the process of editing papers for a book with Mark N Cohen on the rise of ancient technology and its cultural interactions. His scientific papers are now the responsibility of Joan Mishara of the Conservation-Analytical Laboratory of the Smithsonian Institution, Washington DC 20560 USA, and plans are being made for their publication[14].

Ted Wertime's roots went deep into Pennsylvania's history. The family home is a log house which at the time it was built stood on the American frontier. Ted's convictions about our prodigious use of energy led him to build a retirement home into the side of a hill in McConnellsburg that was as energy efficient as solar heating and his ingenuity could make it. It was also beautiful. He enjoyed making music and played the violin in local quartets. He was a steadfast friend, and we miss him.

Martha Goodway

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X-ray fluorescence analysis of the Appleford hoard of Romano-British pewter

A M Pollard

Abstract

Results are presented from an analytical investigation of the Appleford hoard of Romano-British pewter tableware using X-ray fluorescence. Three compositional categories are identified, approximately corresponding to 50%, 75% and pure tin. The correlation between vessel type and compositional category is discussed, and comparison is made with previously published analytical data. The clear relationship observed in the Appleford hoard is not as apparent in the comparative data, although the use of scrap pewter could well explain the discrepancies.

Introduction

When compared with the alloys of copper and the precious metals, Roman lead and tin alloys have received little attention from the analyst. The results obtained by Gowland[1], Smythe[2] and Liversidge[3] have been summarised by Tylecote[4], and bibliographies on the subject are given by Tylecote[4] and Caley[5]. The Roman pewter industry at Camerton, Somerset, is discussed by Wedlake[6], together with a distribution map and catalogue of the finds in Britain. A slightly more recent distribution map has been published by Peal[7], together with suggested typologies of rim type and decoration. The most recent discussion of pewter production in Britain is given by Hughes[8] in his assessment of the composition types of six pewter ingots found in the Thames at Battersea.

The purpose of the present paper is to report the results of an X-ray fluorescence analysis of the twenty-four pewter vessels found at Appleford in Berkshire, and currently held in the Ashmolean Museum. A full account of the circumstances of the find and a catalogue of the objects has been published by Brown[9]. The reference numbers given to the objects in that catalogue are used throughout this paper. Following a description and assessment of the analytical method, the results are discussed in terms of composition as a function of vessel type and size. All the available analyses of similar tableware are summarised and compared with the Appleford results.

The hoard consisted of one flagon, three small plates, several bowls of various sizes and thirteen large plates, ranging in diameter from 30 to 50 cm. Associated iron material included a cauldron chain, steelyard, scythe blade, and some smaller objects, together with stone and pottery fragments, human and animal bones and various organic remains, principally a hob-nailed leather shoe. The hoard is described as a well group built up over several years, but the pewter was probably deliberately hidden in the well. The group is dated to the fourth century.

Experimental

X-ray fluorescence Analysis was carried out on the complete vessels using an energy dispersive system developed at the Research Laboratory for Archaeology specifically for application to archaeological and museum material. It consists of a Kevex-Ray 50kV 1mA Mo transmission target X-ray tube and power supply together with a Link Systems Si (Li) detector (FWHM 165 eV at 5.9 KeV) and associated electronics. The X-ray beam is collimated to an ellipse approximately 2x3 mm at the position of the specimen. In order to obtain an analysis which is representative of the alloy composition, an area of slightly greater extent than the X-ray beam has to be cleaned to bright metal. In the present work this was done by shaving off a thin layer, usually on the rim of the vessel, using a sharp surgical scalpel. The results on the control standard used throughout the measurements indicated that this method gave reproducible results and did not result in a smearing effect of the softer (tin) phase over the harder (lead-tin solid solution). Experiments on the plate used as a test of homogeneity (described below) also indicated that a clean reproducible surface could be obtained which was free from surface contamination. In general, the as-received surface was found to be richer in tin, and to contain copper and iron not thought to be present in the bulk alloy.

It was found practical only to determine the tin, lead and copper content of the alloys. Silver was initially attempted, but was not pursued because of the poor sensitivity. The Minimum Detectable Limit (MDL) was calculated at 0.21% silver in a pure tin matrix. The corresponding figures for lead and copper in tin were found to be 0.10% and 0.06% respectively. The only other element observed was iron, but this was not measured, partly because no standards were available for iron in tin, but also because the iron appeared only to be present in the patina.

Table 1 Composition of the Standards

Standard	% Sn	% Pb	% Cu	% Ag
TL 3	90.0	10.0	-	-
TL 2	85.0	15.0	-	-
RS 'SAVBIT'	50.0	48.5	1.5	-
Fry's 4000	40.0	60.0	-	-
RS 'AL'	18.0	80.0		2.0

A range of commercially available solders were used as calibration standards plus two specially prepared binary alloys. The compositions are shown in Table 1. The procedure used for calculating the concentrations in the samples was the binary ratio method as described by Bertin[10], p 392. Two working curves were constructed from the data on the standards: intensity ($Pb\ L_\alpha / Sn\ K_\alpha$) vs weight percentage (Pb/Sn) and intensity ($Cu\ K_\alpha / Sn\ K_\alpha$) vs (Cu/Sn). The linearity of the Pb/Sn curve was excellent over the range 0.1 – 4.5 %Pb/%Sn. Unfortunately only one standard contained any measurable copper, and the 'working curve' for Cu/Sn was reduced to a simple proportionality estimate. Ratio methods of calculation are ideal for XRF work on archaeological material, because any loss in accuracy is more than compensated by the relative insensitivity to variations in geometry and surface texture between samples and standards. It does, however, implicitly normalise the results to 100%, and assumes therefore that no other element is present above say 0.1%. Inspection of the spectra obtained during analysis can usually confirm this assumption. This method was used for calculating results when the ratio of Pb/Sn was greater than 0.1. When this was not the case a direct calibration curve was used for evaluating the lead content, obtained from TL3 and pure tin.

Accuracy of the Method and Homogeneity of the Vessels

The hoard was analysed in six batches over a period of approximately one year, and it was therefore essential to check carefully the reproducibility of the results. The counts on the standards were checked before each batch, but it was not found necessary to alter the calibration over this time. One of the standards (RS 'Savbit') was used as a test of the precision and accuracy of the results, being measured before and after each analytical session. The results of this are quoted together with the specified composition in Table 2. As can be seen this demonstrates that the method is capable of good results, at least in the 50% Sn region of the alloy composition. A reasonable estimate for the precision of the measurements would be ± 2% relative for lead and tin, and ± 10% relative for copper.

Table 2 Results of Replicate Analyses of RS 'SAVBIT'

		% Sn	% Pb	% Cu
	x	50.00	48.48	1.52
n = 29	s	0.98	0.95	0.15
	CV%	2.0	2.0	9.6
	Quoted	50.0	48 5	1.5

When analysing such large cast objects, it is first necessary to establish the homogeneity of the alloy relative to the precision of the analytical method. For this purpose, one of the large flat dishes was selected (plate 14, diameter 30 cm). The plate was analysed four or five times each at four places on the rim, two areas of the bottom, once on the top and once on the plug used to fill up the central spike hole after the plate had been finished on the lathe. This gave a total of 29 analyses on seven areas of the cast plate, and three measurements on the spike hole plug The mean results for each area are given in Table 3. Using the F-ratio test for the analysis of variance of the means of several groups (e.g. Anderson and Sclove[11], p 555), a value of 3.86 for F with (6,26) degrees of freedom was obtained for areas A to G. The critical values with these degrees of freedom are F (0.05) = 2.599 and F (0.01) = 3.871, resulting in the rejection of the null hypothesis (ie that the alloy composition is the same), at the 95% confidence level but not at the 99% level. This suggests that the composition of the Appleford hoard is likely to be inhomogeneous when compared with the analytical precision. When reporting the results we have, therefore, given a figure which represents the error in the lead and tin content (one standard deviation), expressed as weight per cent metal. The variation in this figure from object to object may be taken as the expected accuracy of the measurements, but is not necessarily representative of the variations in homogeneity – the geometry and size of the vessels resulted in some areas being more difficult to analyse than others, with the corresponding possibility that uncleaned patina may have been included in the irradiated area. A probable example of this is the 6% (metal) standard deviation in the results on the plug shown in Table 3.

Table 3 Homogeneity of Plate 14 – Results of Analyses of Various Areas

			% Cu	% Pb	% Sn
Rim	Area A	n=6	0.05 + 0.04	27.04 + 0.72	72.90 + 0.74
	Area B	n=4	0.05 + 0.05	28.37 + 1.17	7 155 + 1.12
	Area C	n=4	0.07 + 0.05	26.78 + 0.83	73.15 + 0.85
	Area D	n=4	0.08 + 0.03	26.64 + 0.71	73.26 + 0.76
Bottom	Area E	n=3	0.03 + 0.01	28.36 + 0.10	71.59 + 0.14
	Area F	n=3	0.08 + 0.05	28.86 + 0.38	71.06 + 0.38
Top	Area G	n=3	0.10 + 0.02	27.52 + 1.37	72.38 + 1.37
	Plug	n=3	0.12 + 0.01	29.09 + 6.02	70.79 + 6.03
Overall body (A – G)		n=27	0.07 + 0.04	27.55 + 1.10	72 39 + 1.09

Results and Discussion

The analytical data from the 24 pewter vessels in the Appleford hoard are given in Table 4. Where the catalogue[9] indicates that the object was made in more than one section, results for each part are recorded separately, but no attempt was made to analyse all the plugs filling the lathe holes, or more recent patches. A hyphen (-) in the copper column indicates that the copper content averaged over all the measurements was less than or equal to the MDL (0.06%). Figure 1 shows a histogram of the tin content of the 24 vessels, with each analysis plotted separately when a vessel was made in more than one piece. The plotting interval is rather coarse (5%) to avoid any erroneous conclusions resulting from contamination or inhomogeneity.

Three distinct alloy compositions can be seen, corresponding roughly to 50%, 75% and > 95% tin. Hughes[8] has produced a similar plot of the results summarised by Tylecote[4], showing three broad groups corresponding to 30 – 50%, 69 - 80% and > 90% tin. He discussed the origin of these three categories from two viewpoints – the relationship to the

Table 4 Appleford Pewter – Results

Cat No	Description	Overall Diameter cm	No of Measurements	% Cu	% Pb	% Sn	Error in Pb & Sn (% metal)
1	Flagon (a) Body – top	17.0 (Height)	4	0.21	48.1	51.7	0.4
	(b) Body – bottom		4	0.35	50.9	48.8	1.5
	(c) Footring		2	0.09	50.1	49.9	1.7
	(d) Handle		4	1.11	43.5	55.4	1.7
2	Flat Platter	13.3	5	-	0.9	99.1	0.5
3	Fluted Bowl	14.0	7	-	0.2	99.8	0.1
4	Small Plate	14.0	5	0.16	41.9	58.0	1.7
5	Small Bowl (a) Body	15.0	5	-	51.2	48.8	2.5
	(b) Footring		4	0.22	51.0	48.8	1.9
6	Small Bowl	16.0	5	0.08	50.7	49.2	0.9
7	Octagonal Flanged Bowl (a) Body	19.0 max	10	-	18.9	81.1	2.8
	(b) Footring		4	-	61.6	38.3	3.4
8	Shallow Bowl	15.0	5	0.08	54.9	45.1	1.1
9	Shallow Bowl	19.7	7	-	23.7	76.2	1.0
10	Hemispherical Bowl	18.0	10	-	22.2	77.7	1.5
11	Hemispherical Bowl (a) Body	20.0	6	0.08	22.5	77.4	1.5
	(b) Footring		3	0.11	57.7	42.2	0.7
12	Plate	30.4	6	-	23.1	76.9	0.8
13	Plate (no rim)	30.5	7	-	19.6	80.3	1.5
14	Plate	30.0	27	0.07	27.5	72.4	1.1
15	Plate	35.5	4	-	30.0	70.0	1.2
16	Plate	36.0	7	-	20.0	80.0	2.7
17	Plate	36.0	5	-	21.6	78.4	2.8
18	Plate	36.0	5	-	20.0	80.0	1.6
19	Plate	38.5	6	0.08	24.1	75.8	1.3
20	Plate	38.4	6	-	24.3	75.7	1.2
21	Plate	46.0	12	-	22.1	77.9	1.0
22	Plate	45.0	12	-	24.6	75.3	0.9
23	Plate	38.0	8	-	26.4	73.6	2.0
24	Plate	50.0	12	0.12	27.8	72.1	1.8

eutectic point in the tin/lead system (61.9% tin), and from the description of the manufacture of solder in Roman times given by Pliny[12]. Briefly, he argues that the 60 - 80% tin group could have been obtained by mixing metals in the melt to give a narrow 'pasty' stage in the cooling curve (< 20°C). This was possibly intended to yield better casting properties. Pliny gives two recipes for 'argentarium', corresponding to 50% and 67% tin. Thus Pliny's second recipe would yield an alloy very similar in composition to that obtained by controlling the melt as Hughes suggests. The third group (>90% tin) Hughes describes as 'deliberately impure tin', on the basis of several published analyses of Roman tin ingots (eg, Smythe[2]), showing purities in excess of 99.5%. It may be that the very pure ingots are direct from the tin mines, and that those of slightly less purity have been re-used and contaminated, either deliberately or accidentally.

The results from the Appleford hoard may be summarised as follows:

Eleven analyses between 38 and 58% – average 48.7% Sn,
Seventeen results between 70 and 81% – average 76.5% Sn,
Two vessels in excess of 99% Sn.

The first group could clearly correspond to the 50% recipe of Pliny, resulting from the mixture of equal weights of lead and tin. The last two are virtually pure tin, similar to some of the Roman ingots found elsewhere, rather than the 'deliberately' impure type described by Hughes. The majority of the vessels have a tin content close to 75%, with the lower limit of the group being 8% above the eutectic composition, which would correspond to a 'pasty' stage of about 15°C during solidification. It seems unlikely that this composition is an attempt to produce the eutectic alloy. The average is also significantly above Pliny's 67% tin recipe, suggesting a ratio nearer to 3:1 rather than 2:1 Sn:Pb if the material were made by weighing our pure tin and lead.

When considering the correlation between vessel form and alloy composition, it is immediately apparent that the 3:1 (Sn:Pb) group contains all the large plates (numbers 12 – 24) plus the two large hemispherical bowls (10 and 11, diameters 18 and 20 cm), the shallow bowl (number 9, diameter 19.7 cm) and the flanged bowl (number 7, maximum diameter 19 cm). None of the remaining vessels have a maximum dimension exceeding 16 cm, and we can safely conclude that the larger vessels were all cast from an alloy of approximately 3:1 Sn:Pb. That this was a deliberate choice is suggested by the fact that the separate footrings of vessels 7 and 11 were made from a more lead-rich melt. When looking for a reason for the use of tin-rich alloy for these large vessels, we may recall that the liquidus of the Sn/Pb system rises sharply below the eutectic point, giving a longer 'pasty' stage and therefore making the cheaper alloy more difficult to cast. Modern tests, however, have shown that eutectic alloy is even more castable than tin-rich melts at the same temperature above the liquidus.[13] Two of the smallest objects in the hoard were cast from virtually pure tin (vessels 2 and 3). Dish number 3 is quite ornate, with decoration cast in low relief on the upper surface. Pure tin would, of course, solidify at a unique temperature (232°C) and should therefore be easier to cast than non-eutectic pewter, but the resulting vessel would be considerably softer than one made from pewter.

In the catalogue of the hoard it was noted that several of the plates were matching pairs: plates 17 and 18: 21 and 22 although 22 is not decorated; and 23 and 24, although 24 is larger. Using Student's t-test for the equality of means, and assuming unequal population variances, (eg, Anderson and Sclove[11], p 444), we find that the tin contents of plates 17 and 18, and 23 and 24 are the same at the 95% level of confidence, but those of plates 21 and 22 are not. It is quite possible, therefore, that plates 17, 18 and 23, 24 were made from the same melt. Plate 21 is decorated with an engraved roundel in the centre of the upper side which is parallelled by that on plate 9 in the hoard found at Appleshaw, Hampshire[14]. Unfortunately, this was not one of the vessels from that hoard analysed by Gowland[1].

In order to compare the composition of the Appleford hoard with previous analyses of Romano-British pewter, I have compiled a summary in Table 5, which contains all the vessels which may be considered as tableware. The results are taken principally from the work of Gowland[1] and Liversidge[3]. Dimensions, where available, have been converted to centimetres. Also included are the analyses of two of the several pewter patera found during the recent excavations at Bath, taken from a much larger body of data about to be published on the 'lead' curses and small-finds from that excavation[15]. These may be regarded as exceptional results, in that the patera were probably not intended as tableware, but they are sufficiently similar to warrant inclusion.

The distribution of tin in these objects is shown in Figure 2, again with a 5% plotting interval. As before, three groups are apparent: 40 - 50% (3 objects, average 44.7%); 60 - 80% (17 vessels, average 71.5%) and > 85% (11 samples, average 94.2%). The lower group clearly overlaps with the 38 - 58% group from Appleford, and again is probably Pliny's 50/50 recipe. The high tin group is better represented than at Appleford, and only two objects (Table 5, number 4 and 5) are 'pure' tin, such as was found in the Appleford hoard. The remaining nine examples in this group are more like the 'deliberately impure' tin suggested by Hughes (average tin content 93%), and as such are not represented at Appleford. The intermediate group is also more difficult to match; whilst the majority lie between 70 and 80% (as in the current data), five objects fall below 70% tin, lowering the mean to 71.5%. It is possible that these five were an attempt at the eutectic composition, or manufactured according to Pliny' 2:1 recipe, and that the remainder are in the proportions of 3:1 as postulated above.

It has proved more difficult to correlate the vessel types with the alloy composition, partly because insufficient data was published about the objects at the time of the analyses, but also because the correlations are not as clear as those described above. At Appleford, the 50% tin group contained most of the smaller vessels; platters and bowls with a diameter up to approximately 20 cm. In Table 5, number 15 has such a composition but is described as a large plate (dimensions not given), whilst number 3 is a 'cup' (more likely a flagon), with a height between 20 and 35.5 cm. In the current data, the 3:1-type vessels are invariably the larger bowls and the large plates. Many of the vessels in this category in Table 5 are smaller than these (eg numbers 9 and 10), although dimensions are not available for much of the East Anglian material. The comparison between the high tin vessels is better, in that all the objects of this type are small, with the major exception of the large dish from Appleshaw (Table 5, number 7), which is the largest of all the vessels whose dimensions are recorded.

A survey of the comparable material does not, therefore, yield the degree of support which one might have hoped for. That this is so need not be surprising – the pewter industry certainly would have used a large amount of scrap metal to produce new vessels, and the Romans would have had few ways of assessing the tin content of scrap pewter, apart from observing its behaviour on solidification. Once a significant proportion of scrap was introduced into the melt, its composition would become largely unknown. The relative homogeneity in the distribution of the tin contents of the Appleford hoard perhaps suggests that this group represents a collection of vessels not made using scrap pewter, and

Table 5 Published Analysis of Romano-British Tableware

Description	Provenance	Dimensions (cm)	% Cu	% Pb	% Sn	Reference	
						Description	Analysis
1 Cup	High Rochester, Redesdale	ht 4, rim d 9, base d. 4 5	nil	4.49	95.64	17	2
2 Jug	Shapwick, Glastonbury	ht 19	nil	12.22	88.00	18	2
3 Cup	Brislington Well, Bristol	ht ?20 - 35.5	nil	54.80	45.38	19	2
4 Cup	Melandra Castle, Derbyshire	d 7.5	tr	tr	100	2	2
5 Small Oval Dish	Appleshaw 32	23 x 11.5		0.14	99.18	14	1
6 Bowl	Appleshaw 27	ht 6.5, d 20	tr	5.06	94.35	14	1
7 Large Circular Dish	Appleshaw 2	d 56		8.31	90.55	14	1
8 Chalice Cup	Appleshaw 12	ht 11.5		23.04	76.41	14	1
9 Shallow Dish	Appleshaw 28 (Chi-Rho)	d 11		26.09	72.36	14	1
10 Flanged Cup	Appleshaw 19	d 11, ht 5		27.62	70.58	14	1
11 Large Circular Dish	Appleshaw 4	d 47		34.66	64.75	14	1
12 Square Dish	Icklingham, Suffolk	breadth 37	tr	27.32	71.80	20	1
13 Shallow Circular Dish	Southwark, London (Martinus)	d 29		26.75	72.90	21	1
14 Octagonal Dish	Icklingham, Suffolk	breadth 24	tr	53.34	45.74	20	1
15 Large Dish (83.774)	Whittlesea Mere, Cambridgeshire	d 32		57	43	22	3
16 Large Dish (51.344a)	Abington Pigotts, Cambridgeshire			37.7	62.3		3
17 Large Tazza (22.753)	Sutton, Isle of Ely	ht 10, d 22		37.8	62.2	23	3
18 Large Dish (1891.41)	Sutton, Isle of Ely	d 39.6		32.2	67.8	23	3
19 Tazza (22.755)	Isleham Fen, Cambridgeshire			27.5	72.5	22	3
20 Pedestal Bowl (22.758)	Isleham Fen, Cambridgeshire	ht 6, d 14		24	76	22	3
21 Dish (22.752)	Isleham Fen, Cambridgeshire	d 19.5		30.8	69.2	22	3
22 Dish (-es?) (H192a,b)	Icklingham, Suffolk	a) base		21	79		3
		b) rim		20.5	79.5		3
23 Small Dish (5 1344b)	Abington Pigotts, Cambridgeshire			30	70		3
24 Tazza (1914.107.9)	Mildenhall, West Row, Suffolk			25.75	74.25	21	3
25 Large Dish (1914.107.2)	Mildenhall, West Row, Suffolk			26.65	73.35	21	3
26 Patera (X2321)	Bath	ht 5.5, rim d 10, base d 6 a) handle		6.4	93.5	15	15
		b) body		3.7	96.2		
27 Patera (X2320)	Bath	ht 5, rim d 9-10, base d 5.5 a) handle		3.0	97.0	15	15
		b) body		3.3	96.7		

Table 5 (contd)

	Description	**Provenance**	**Dimensions (cm)**	**% Cu**	**% Pb**	**% Sn**	**Reference Description**	**Reference Analysis**
28	Flagon	Bosence Cornwall		10	3	85 (Fe 2)	16	16
29	Inscribed Bowl	Bosence Cornwall		<0.5	15	85	16	16

Notes

Number 1	Smythe[17] suggests that this cup was wrought, not cast.
Number 3	Seven vessels were found, three of which are illustrated by Barker[19]. The heights are given as ranging from 195 to 355 mm. An analysis of one is given, but is later doubted by Smythe[2].
Number 18	Six dishes were found at Sutton, the dimensions given as between 300 and 485 mm
Number 22	The object is described as a 'dish': two 'dishes' are recorded in the Icklingham hoard – no 5, circular, diameter 300 and 318 mm, and no 9, oval, broken, original length probably 215 to 228 mm (drawing of fish stamped or incised).
Number 28	This analysis is not plotted. It contains much more copper than normal.

therefore either relatively early (most pewter can only be dated to the fourth century, except the material from Bath), or held by one family for a long period, but this can be no more than speculation.

Peal[7] has suggested that the distribution of pewter finds in England can be divided into four zones – South West, Fens, Northamptonshire and London, and speculates about the possibility of centralised pewter production in these areas. On this hypothesis, Appleford would probably be included in the South Western group, whose major source of manufacture is supposed to be the well-documented site at Camerton[6]. However, an increasing number of pewter moulds have been found all over Roman Britain, and it would appear that the idea of centralised production in a small number of regions should be abandoned in favour of a much more widely distributed and perhaps itinerant manufacturing model. Recent evidence for widespread production has been discussed by Brown[16]. It is possibly better, therefore, not to speculate on the manufacturing source of the Appleford hoard, although more sophisticated methods of analysis would almost certainly be able to pinpoint the sources of the lead and tin ores used. The most likely result of such work would surely be Mendip lead and Cornish tin.

Conclusions

The alloy composition of the Appleford hoard can be neatly divided into three categories:

i) 50% tin. Mostly small vessels, with maximum dimensions less than 20 cm. Probably the 'counterfeit stagnum' described by Pliny as being 'equal weights of white and black lead' (ie, tin and lead).

ii) 75% tin. Larger bowls and all the plates. Probably not the 2:1 mixture described by Pliny, or an attempt to produce the eutectic composition for ease of casting, as suggested by Hughes. A 3:1 recipe seems most likely.

iii) Two small plates (diameter 13-14 cm), of virtually pure tin.

It appears that these three compositional categories were derived from definite recipes formulated for the type of vessel required. Comparison with previously published results does not entirely agree with the above groupings, but this is not unexpected in view of the likely re-use of old pewter and the subsequent lack of definition in the composition. The relative clarity of the Appleford results suggests that the hoard was not made from scrap material, and therefore that the vessels may have been made early in the history of pewter in England.

Acknowledgements

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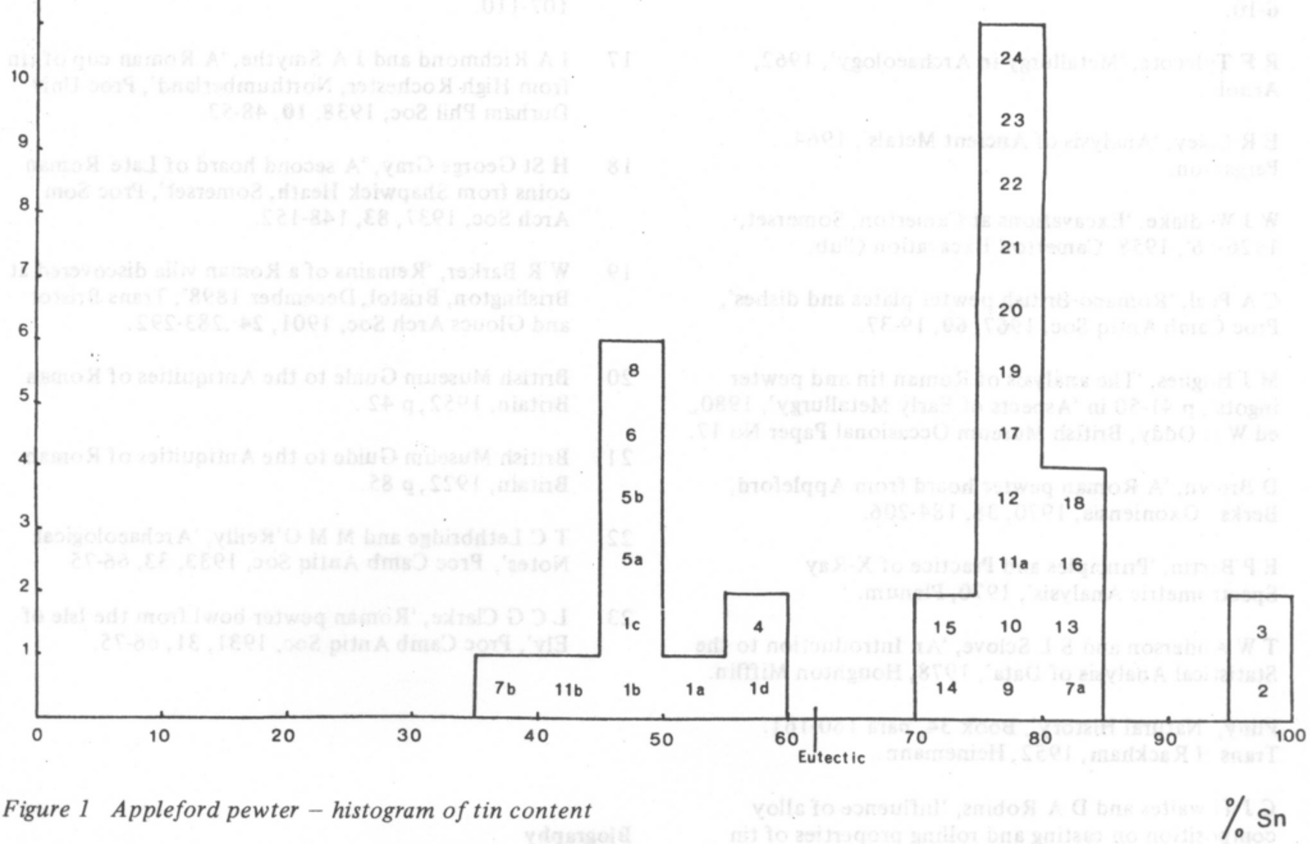

Figure 1 Appleford pewter – histogram of tin content

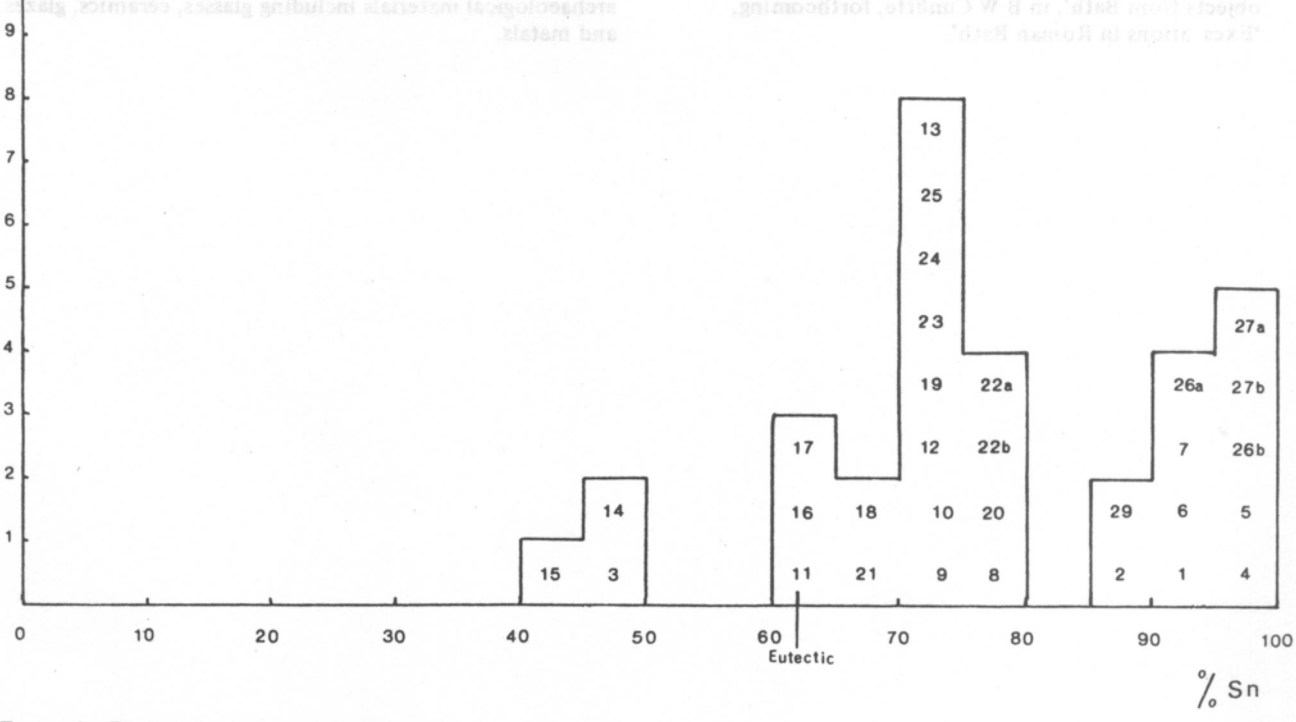

Figure 2 Tin content of comparable vessels

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Biography

Mark Pollard graduated from York University with a degree in physics, and remained at York to obtain a DPhil for x-ray fluorescence and surface studies of the corrosion behaviour of medieval window glass. He was appointed Analytical Research Officer at the Research Laboratory for Archaeology, Oxford University, and has since studied a wide range of archaeological materials including glasses, ceramics, glazes and metals.

English iron for American arms: Laboratory evidence on the iron used at the Springfield Armoury in 1860

Robert B Gordon

Summary

English iron for American Arms: Laboratory Evidence on the Source of Iron used at the Springfield Armory in 1860.

Microprobe analyses of the compositions of slag inclusions in samples of wrought iron have been used to distinguish between some of the sources of iron for rifle barrels used by American armories in the mid-nineteenth century. The iron used for welded rifle and musket barrels is usually of high quality and the products of different works are difficult to distinguish on the basis of their microstructure. The Springfield Armory is reported to have used only iron from Marshall's works in England for a number of years. Comparison of analyses of the slag in a rifle barrel made at that time, a sample of Marshall iron from the Percy collection, and a sample of American barrel iron confirms the use of Marshall iron at the Armory.

Introduction

Factories in the Connecticut Valley began the manufacture of mechanisms with interchangeable parts in the early decades of the nineteenth century. The Springfield Armory was an important centre of manufacturing innovation through the work of Armory employees and outside contractors, who supplied both parts and machinery. The methods of production developed at this time became known as the American System of manufactures and it was to the machine builders of the Connecticut Valley that the British Government turned to in 1855 to equip the Enfield Armory[1].

Although great advances were made by the manufacturers of machines and mechanisms in New England, ferrous metallurgy remained a vexatious problem for them. Thus, the Springfield Armory is reported to have become entirely dependent on imported steel and on iron from a single English manufacturer in 1860[2]. This was a cause of much concern during the first years of the American Civil War because of fears that English would cut this source of supply and so cripple the largest Federal armory.

The English ironmaker was Marshall's works in Wednesbury and samples of their product survive in the Percy Collection (now in the Science Museum, London). I report here the results of laboratory examination of a rifle barrel made at the Springfield Armory and of samples of contemporary English and American gun barrel iron. The tests were done to see if the provenance of the iron used at Springfield in 1860 can be determined and to find the reason for the high reputation of the Marshall iron.

Historical Background

The Springfield Armory was founded (in 1794) when the new Federal Government realized that a domestic source of standardized small arms was needed. Although another national armory was put up at Harpers Ferry (Virginia) a few years later, the Springfield Armory was the centre of innovation in small arms manufacturing techniques[3]. Because many of the records of the Springfield Armory have survived, technological innovation there is particularly well documented.

Welding rifle barrels was the most difficult operation in nineteenth century arms making. Barrels were formed and welded from flat skelps under a trip hammer; the labour was heavy and the results uncertain, as shown by the high failure rates in proof testing. It was this operation that was most sensitive to the quality of the iron used. Bar iron from the Salisbury District of Connecticut was considered best for this purpose in America[4]. However, many letters in the Springfield Armory papers show that great difficulties were experienced in obtaining an adequate supply of this iron in the requisite quality. For example, Seman Church of Canaan, Connecticut, wrote to Major Ripley, the Superintendent at Springfield, on 12 December 1845 to say[5]

> *We have made a contract for 50 tons of pig iron to be made entirely from the ore of Salisbury old hill from which to make the 20 tons of barrell iron. We feel a confidence that we will not be deceived – if however when we come to refine it we find there has been an admixture of ores we shall not make it into musket iron and consequently shall not fill your order until we can do so from metal satisfactory to ourselves – We have had so much trouble with iron at the armories s particularly at the Ferry within the last four or five years that we are determined to deliver no more unless of the last kind & this we think can only be from the Salisbury old hill ore or that of the same quality –*

Seman Church's belief in the special qualities of certain ores as the key to the quality of his product is of interest.

Because of the many difficulties encountered with welding barrels under the trip hammer, Superintendent Rosewell Lee at Springfield began experiments on forming the skelp and welding with rolls. The work was done by Henry Burden between 1825 and 1833, but did not result in a practical operation[6]. A further attempt to weld rifle barrels in rolls was made at Springfield in 1850 using machinery built by the Ames Company of Chicopee[7] but in 1851 the commandant of the Armory reported that roll welding was a failure[8]. Later experience suggests that the failure may have been due to the lack of suitable iron rather than a deficiency in the machinery. The British committee on arms-making machinery that visited Springfield in 1854 described the system of forging barrels by trip hammer then in use as inferior to the rolling mill method used in England. However, this committee ordered a set of American production machinery for the Enfield Armory from the Connecticut Valley tool builders that served the Springfield Armory. (One of these machines may be seen in the Science Museum, London). Reports on the English method had been received from Major Hagner in 1848 , Major Mordecai in 1856[9] and from J T Ames (letter to Superintendent James Whitney, 3 Nov 1857). In 1858 an agreement was made for Ames to acquire an English rolling mill and 50 tons of iron to use with it (J Whitney to Ames, 1 Jan 1858)[10].

Subsequent developments can be traced through the Armory correspondence: On 19 June 1858 Whitney wrote to C & F Thomson of Boston "'. . machinery for rolling barrels has not yet arrived from England". On the 1st of July Whitney wrote to Ames to arrange for the employment of William Onions of England to set up the machinery at Springfield. On 1 November Whitney, responding to a query from Ames, reported that proof tests had been done on the first lot of 100 rolled barrels and that only one of these had failed; he observed that the rolling machine was regarded by the Master Armorer as a 'perfect success'. Thus, the roll-welding machine must have been set up sometime after July 1st, 1858, and have been in successful operation by November 1st, a remarkably short start-up time for so complex a manufacturing operation.

A description of the barrel roll-welding operation is found in an account of the Springfield Armory written by G B Prescott in 1863[11]:

> *The scalps are first heated in the blaze of a bituminous coal furnace, to a white heat – to a point just as near the melting as can be attained without actually dropping apart – and are then passed between three sets of rollers, each of which elongates the barrel, reduces its diameter, and assists in forcing it to assume the proper size and taper . . The operation of rolling the barrel is not only a very important and valuable one, but very difficult of acquisition, the knowledge appertaining to its practical working having been wholly confined to one person in the country previous to breaking out of the Rebellion.*

This one person must have been Mr Onions. But after the War began, four additional sets of rolls were imported and other workers learned the necessary skills.

The iron used in the barrel rolling process is identified in a letter from J Whitney to Ames (7 December 1858)[12]:

> *You are hereby authorized to furnish for this Armory One Hundred Tons (2240 lbs each) English (Marshall) Iron for gun barrels . . Price not to exceed$ 200/ton.*

No other iron would do (J Whitney to Halicht 8 April 1859)[13]:

> *. . . we have recently introduced at this Armory Machinery for Welding barrels by rolling . . Bar iron will not answer for our present use . .*

When the Civil War began there was much concern that England would cut off the supply of Marshall iron and efforts to find an American-made substitute were put in hand. For a long time there was no success. One disgruntled ironmaster complained,

> *[The Ordnance Department] is so very certain to condemn American iron although it may stand five times the charges and wear of the pet Marshall British iron . . So long as the head of the Bureau is anti-American, no workman dare counteract his foreign traducers without fear of dismissal.*
> (James M Hopkins to Dyer 20 September 1861)[14]

It was not until 1863 that the Ordnance Department felt confident enough of the quality of iron produced by an American company to cancel all foreign orders for barrel iron. The replacement product was made by the Trenton Iron Co. but difficulties with the quality and uniformity of the iron supplied remained a serious problem for the Springfield Armory and for private arms contractors throughout the War period[15]. It was not until 1873 that wrought iron was replaced by steel for making rifle barrels at Springfield.

We infer from this episode that the quality of the Marshall iron must have been one of the major factors contributing to the success of the roll welding of barrels and that whatever was special about this iron was not easy to duplicate with the iron-making technology in use in America in the 1860s. This is the more surprising in that the Salisbury District had established a reputation as a source of the finest quality gun barrel iron in the early decades of the century. Since there are no written records to give us a technical description of the Marshall iron, we rely on examination of specimens to find out what made it such an unusual material.

Metallographic Evidence

A sample was obtained from the barrel of a Model 1855 U.S. Springfield Percussion Rifle-Musket. Since this weapon had an iron forend, (a modification introduced in 1859) it must have been made between 1859 and 1861, when production of this model stopped[16]. It would therefore have been a roll-welded barrel. For comparison, a sample of Marshall iron was obtained from the Percy Collection in the Science Museum (London). The label on the Museum specimen states:

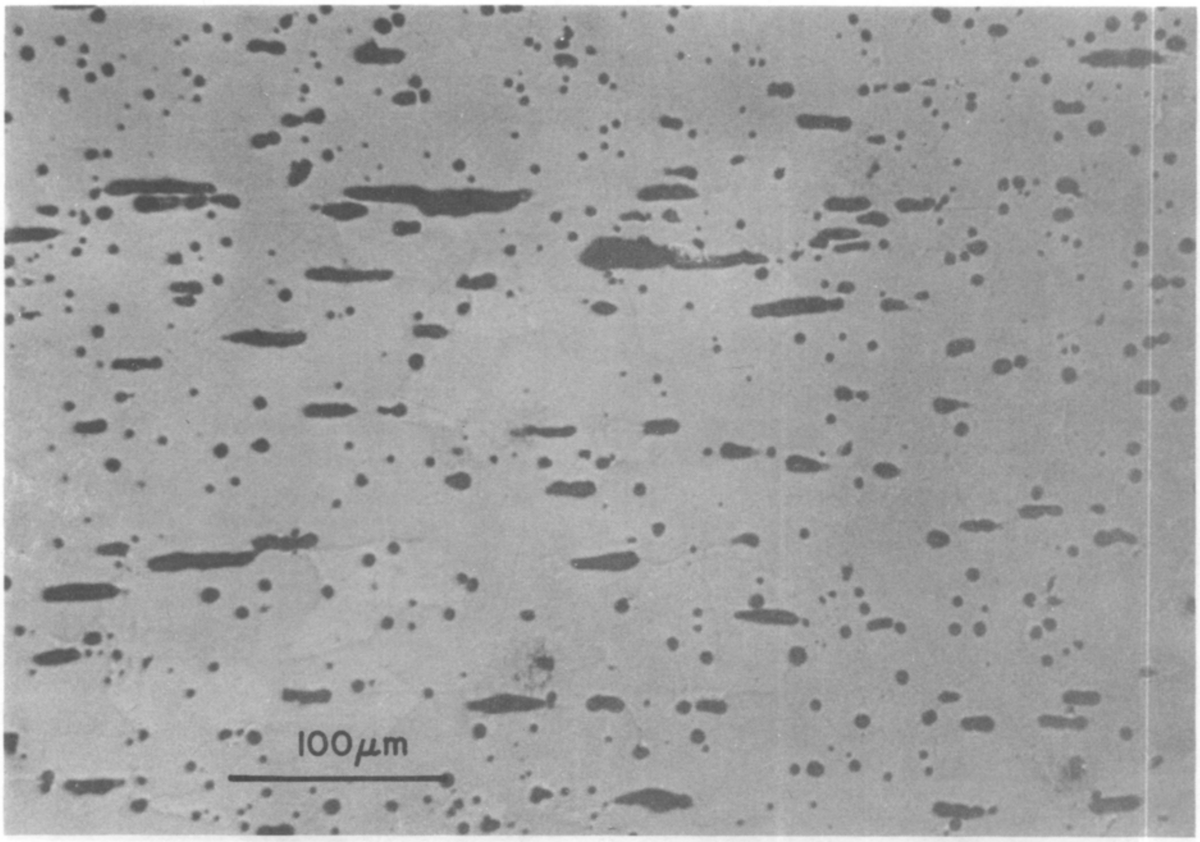
> *Marshall's Barrel (Gun) Iron, Wednesbury. See Ms page opposite p.710 of my lecture copy (interleaved) of Iron & Steel 1864 for a description of its manufacture in 1855 by the late Mr Frazer (Gun Factory, Arsenal). This iron is used with great success for Coils of Armstrong Guns at the Arsenal (A.D. 1864). Much sounder welds have been obtained with it than with Taylor's (of Leeds) iron previously used at the Arsenal. Fracture said to be remarkably clean & uniform. – J Percy. Aug. 24, 1855 .*

Also examined for comparison was a section from a barrel excavated during an archaeological study of the site of the Eli Whitney Armory (Whitneyville, Connecticut). The barrel iron used at the Whitney Armory was obtained from the Salisbury District of Connecticut (Canfield & Robbins to Ripley, 28 October 1845; E Whitney to M & S Peters, October 30, 1843)[17] but after 1848 steel was used[18]. This sample is therefore considered to be representative of the iron being supplied by Salisbury ironmasters for the Connecticut arms industry.

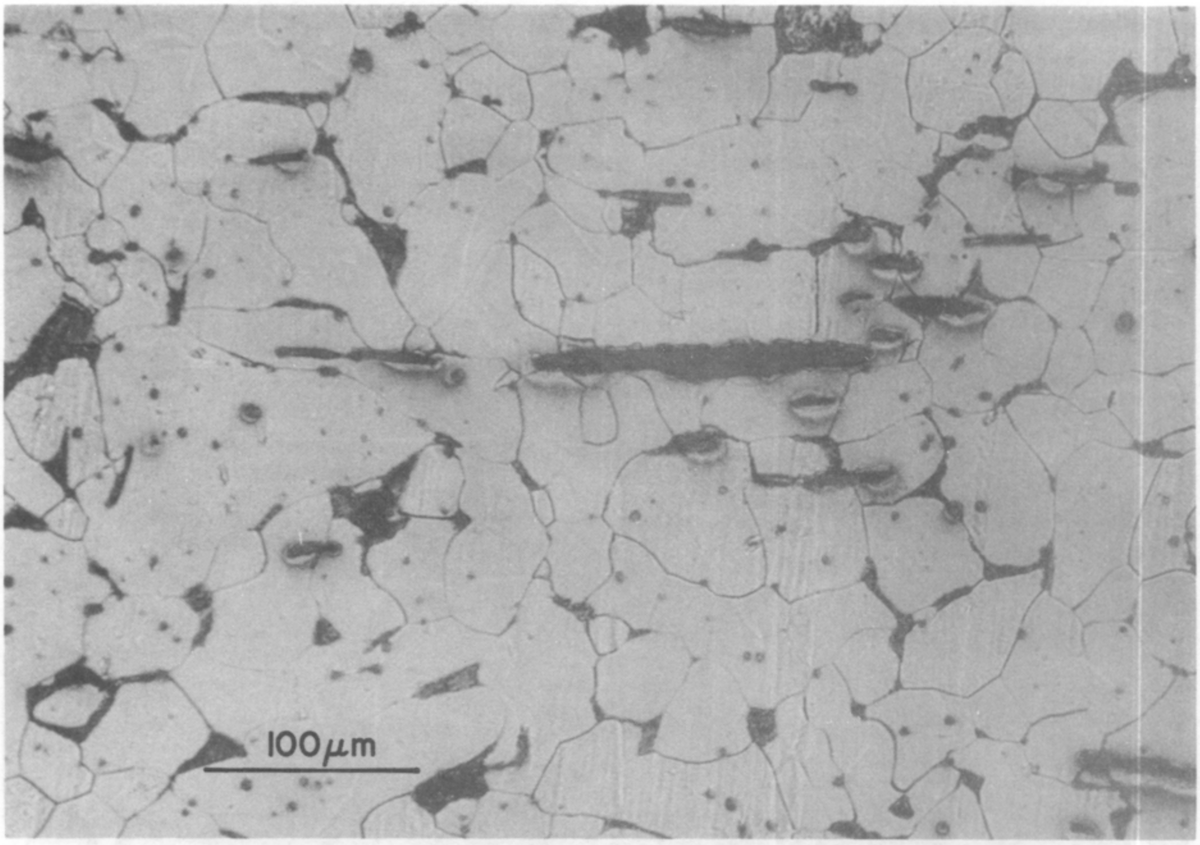
Marshall Iron. Figure 1a shows the polished but unetched longitudinal section of the Marshall iron. It contains remarkably uniform distribution of fine slag fibres, which could only be obtained with very extensive mechanical working of the metal by hammering and/or rolling. A uniform distribution of fine slag would facilitate welding the iron since in welding wrought iron, the slag forms a protective liquid cover on the surfaces to be welded before they are bonded together. A uniform slag distribution would be particularly important in roll welding since there would be no opportunity for the welder to rework places where there was an excess or deficiency of slag by means of extra hammering, as could be done in the old process.

Figure 1b shows the sample at the same magnification as Fig 1a after etching. The ferrite grain size is small and uniform. This should make the iron deform as an isotropic material during rolling. Most samples of wrought iron have a non-uniform ferrite grain size and would not flow in so reliable a manner in forming operations. Figure 1c shows the etched sample at high magnification; small areas of fine pearlite are present. This shows that the carbon was not completely removed from the iron during the puddling process. The pearlite would increase the strength of the

1a



1b



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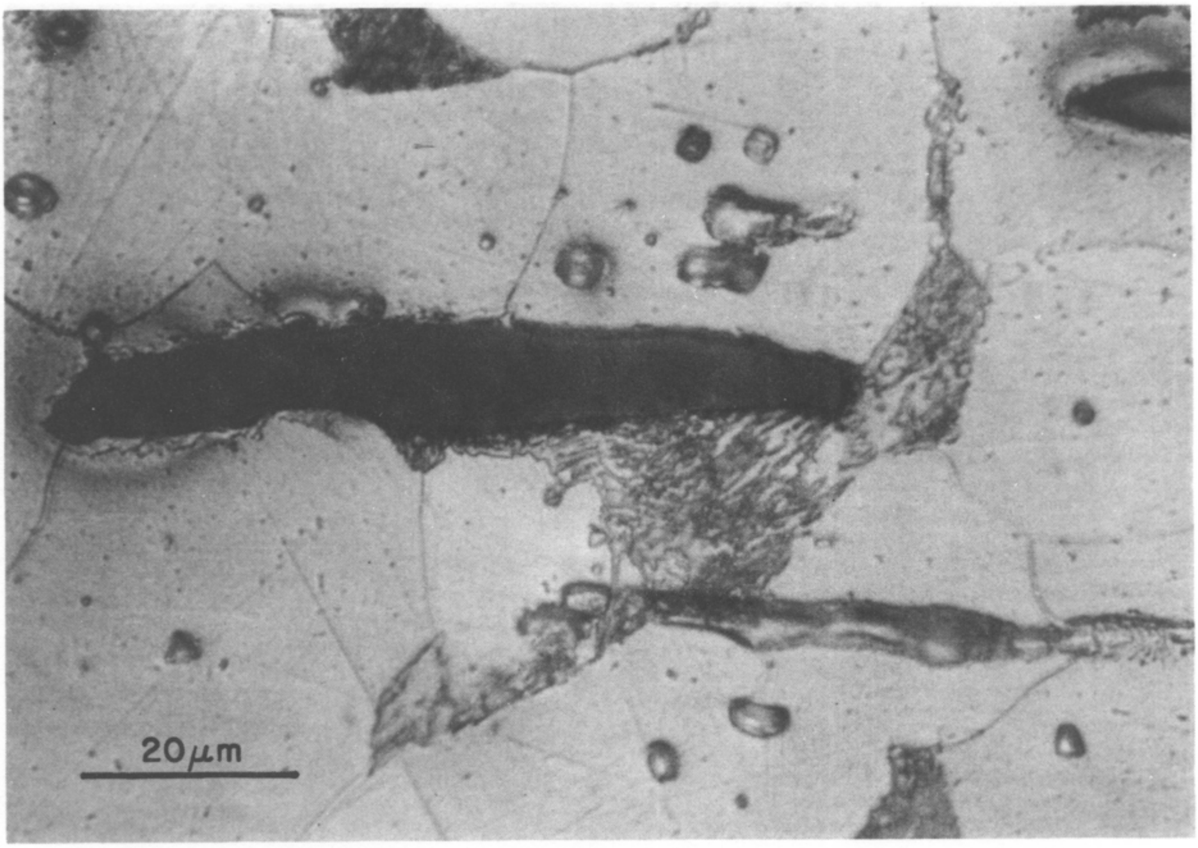

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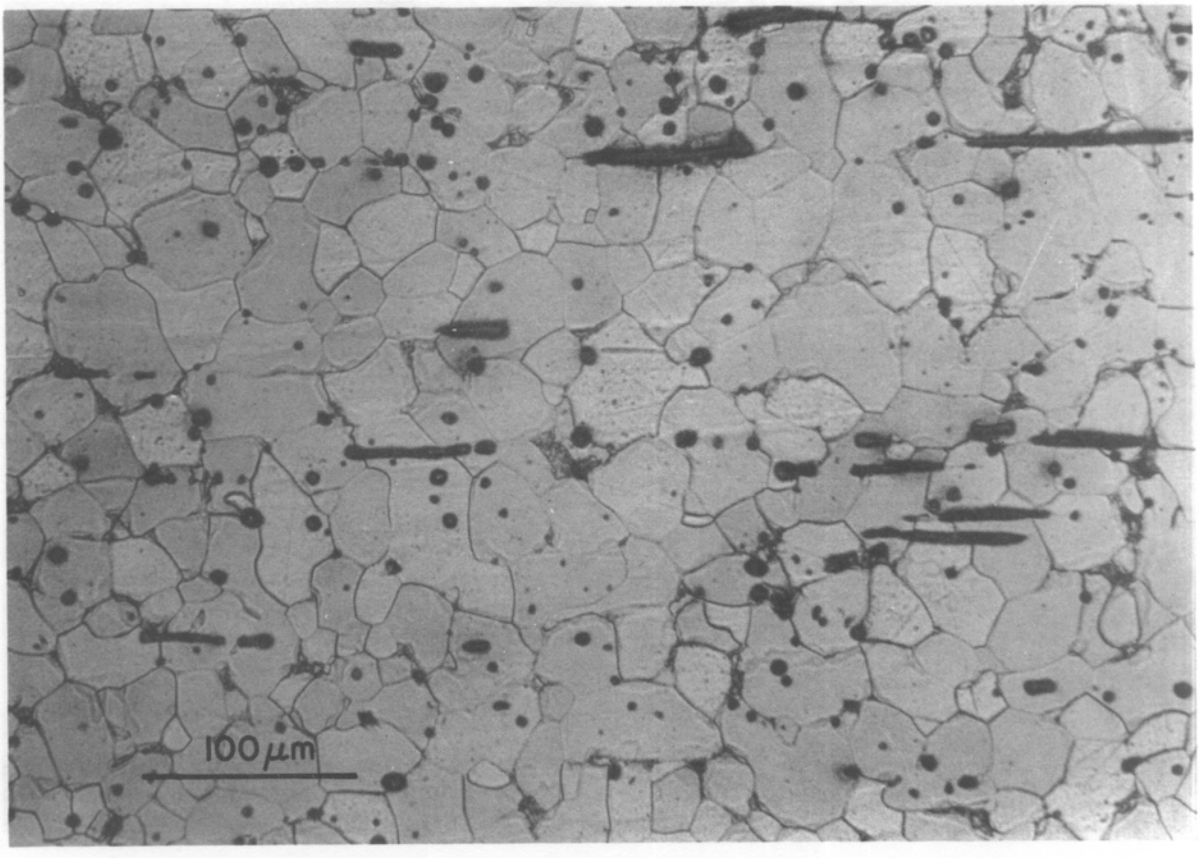


iron without greatly reducing its ductility. The ferrite grain boundaries are free of the carbide precipitates that are frequently found in wrought iron. This is also expected to improve its mechanical properties because the carbide-ferrite interface is often a site for crack nucleation[19]. (The small holes seen in Fig 1c are places where slag particles have been plucked out during polishing of the specimen). Fine etch pits are visible within the ferrite grains; these are probably nitride precipitates[20]. The slag particles in this sample appear to contain a single phase only.

The microstructure of the Marshall iron shows that it is remarkable for its fine, uniform ferrite grain size and slag filaments. It contains more pearlite than wrought iron made at this time usually contains.

Springfield Barrel. Figure 2a is at the same magnification as Fig 1b and is of a specimen prepared in the same way. The structures are very similar, although the metal from the Springfield rifle barrel has a slightly finer grain size. Ferrite grain size is not a good indicator of provenance since it will depend on the mechanical and thermal treatment that the iron receives after it leaves the mill – in this case it would have been rolled into skelps and then passed through the welding rolls at very high temperature. At high magnification the Springfield sample (Fig 2b) is very similar to the Marshall iron: the slag appears to contain only a single phase, there is a small amount of pearlite present, and the ferrite grains are marked by etch pits.

Whitney Armory Barrel Iron. To judge if similarity of structures is good evidence that the Springfield rifle barrel is made of Marshall iron, we need to know the range of iron structures found in wrought iron produced by different makers. Salisbury barrel iron would be the nearest comparable wrought iron from a different source. At low magnification (Fig 3a), the microstructure of the sample obtained at the Whitney Armory site looks very similar to the Marshall iron but at high magnification (Fig 3b) some distinct differences are evident: there is little or no pearlite present. The ferrite grains are more nearly free of etch pits; instead, a thin film of carbide precipitate is visible in the ferrite grain boundaries. At the highest optical magnification the slag appears as a fine, polyphase structure, unlike the slag in the Marshall iron.

A quantitative comparison of the microstructures of the three iron samples was also made. Micrographs were taken at locations equally spaced along a line perpendicular to the rolling direction in each sample. The volume fraction of slag, $(V_v)_s$, at each location was determined from point counts made with a grid placed on the micrographs[21]. Intersections with test lines were used to find the average grain size, GS, the mean free distance between slag particles, λ and the shape index of the slag fibres, Q. The results are presented in Table 1. The sample from the Springfield rifle barrel has a lower slag content and a longer mean free distance than the other two samples but the difference is hardly outside the variation within the samples. The slag particles in the sample recovered from the Whitney Armory site are distinctly blunter than the others. This again suggests that the Whitney material is from a different source but better evidence is obtained from chemical analysis of the slag inclusions.

Table I

Structural Characteristics of Barrel Iron

Material	Location in Sample	$(V_v)_s$	GS (mm)	λ (mm)	Q
Marshall	Edge	13.0%	0.038	0.14	7.7
	Centre	8.5	0.039	0.11	7.9
	Edge	8.0	0.042	0.09	5.0
Springfield	Edge	7.3	0.023	0.18	2.3
	Centre	6.8	0.026	0.32	4.0
	Edge	4.8	0.023	0.16	3.4
Whitney	Edge	13.1	0.047	0.07	1.7
	Edge	8.2	0.047	0.10	1.3

Notes

$(V_v)_s$ = volume fraction of slag.
GS = ferrite grain size
λ = mean free distance between slag particles
Q = shape index (length/width) of slag particles

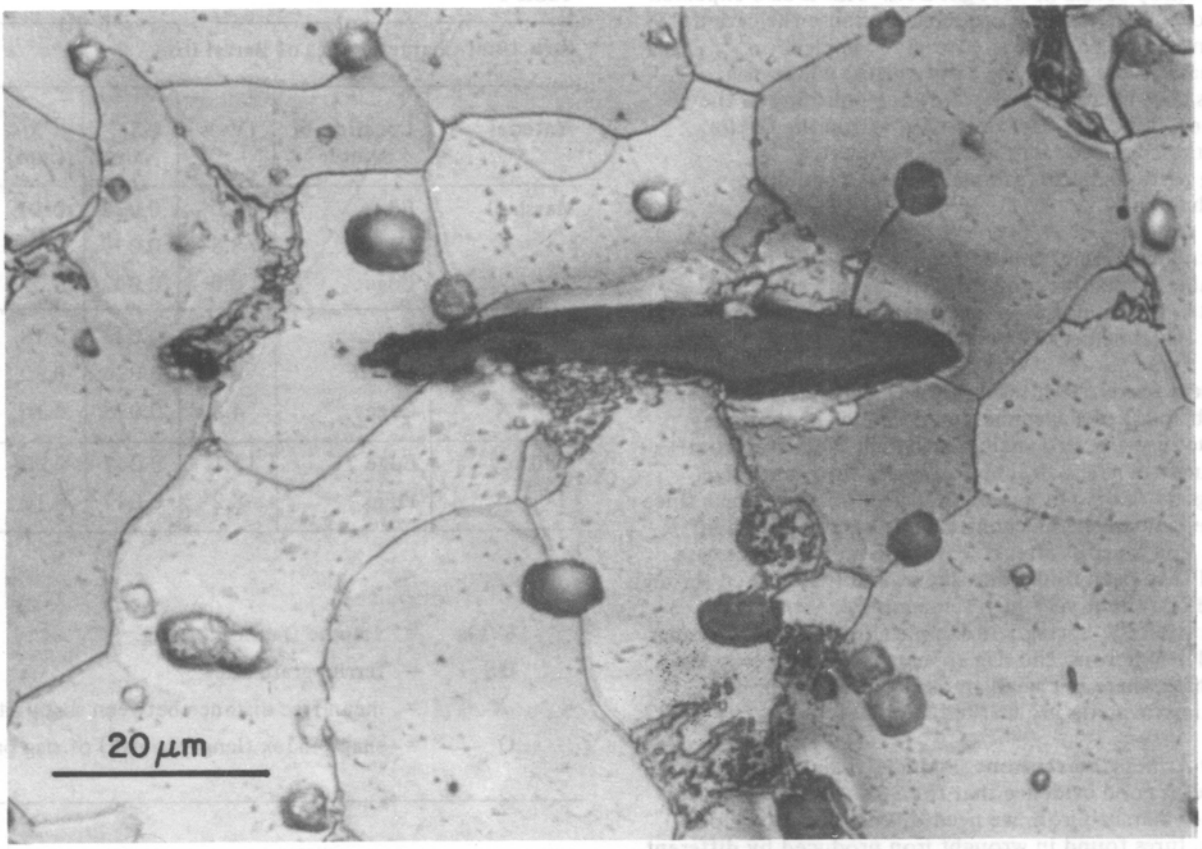
Analysis of Slag Inclusions

Most of the constituents that distinguish one iron ore from another are not reduced and pass into the slag when iron is smelted in a bloomery. Hence, analysis of the slag is likely to be more helpful in determining the provenance of iron than is analysis of the metal itself. Many analyses of slags collected at bloomeries have been published; the microstructures and mineralogy of bloomery slags have been reviewed by Morton and Wingrove[22]. The composition of samples collected at smelting sites may have been altered by weathering; slag included in the metal is protected from weathering but its composition may change slightly by reactions with the surrounding metal during cooling from forging or working conditions. Analyses of slag inclusions in bloomery iron have been performed by Todd and Charles[23], on metal made in Ethiopia, and by Hedges and Salter[24] on English iron currency bars. By means of factor analysis Hedges and Salter were able to differentiate between currency bars from different localities.

The samples of wrought iron examined here would have been made by an indirect process, the Marshall iron by puddling and the iron from the Whitney armory site in a finery. The composition of the ore used to make the pig would be reflected in the composition of the slag included in the metal only to the extent that elements in the ore were retained in the pig and not lost in the blast furnace slag. The composition of the slag inclusions in the iron samples would, however, accurately represent the slag that was used in the puddling furnace or finery; this could be expected to be chracteristic of both the pig used and the details of the refining process employed at the works in question.

Electron microprobe analyses of the slag inclusions in the three samples were made on a Tracor Northern TN200 energy dispersive X-ray analyzer attached to a model MS64 Acton Laboratories microprobe. The accelerating potential was 15 kV and the sample current, 5μA. Each run was recalibrated against the Si and Zn peaks of willemite. Data were reduced according to the method of Bence

2b



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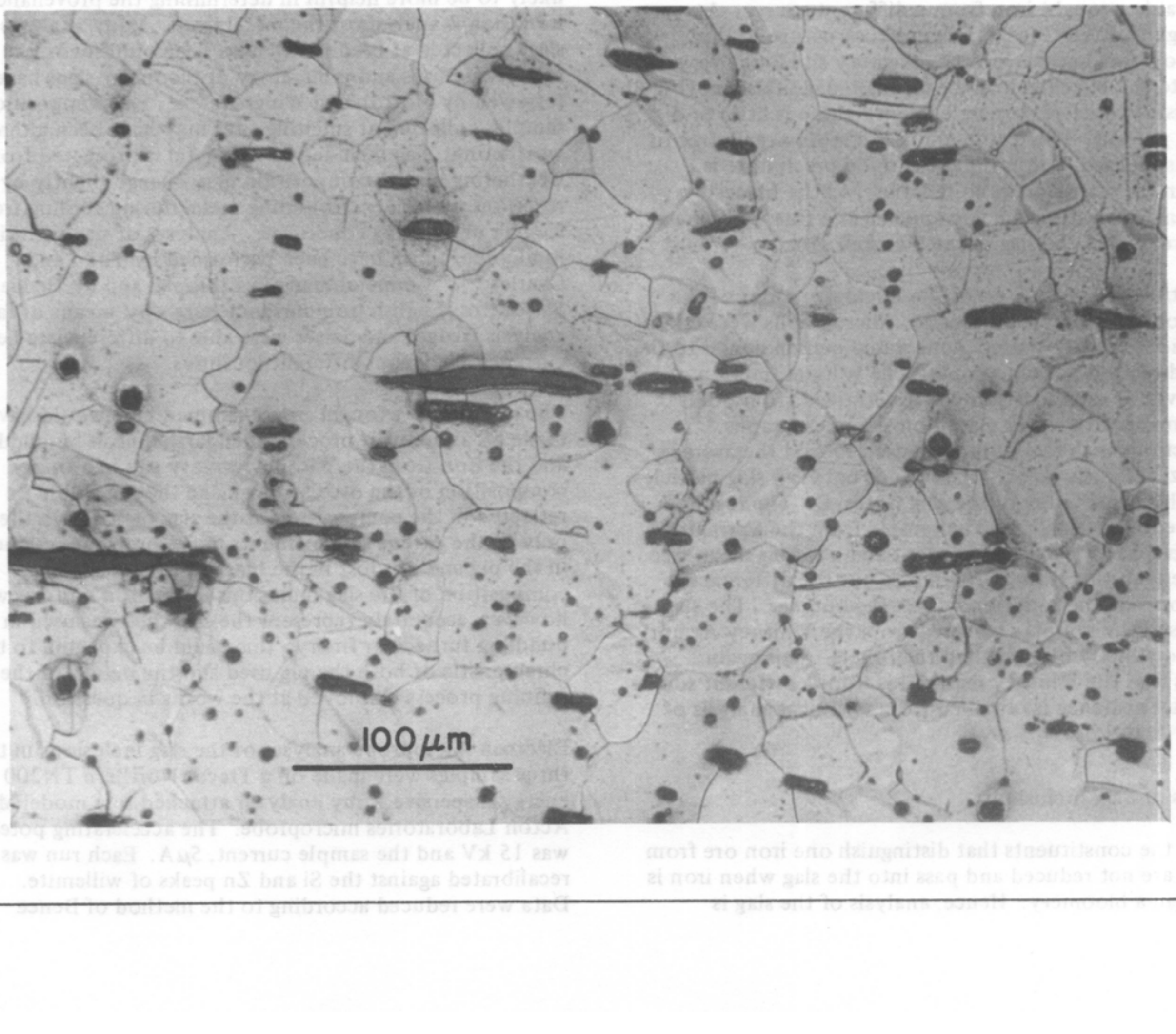

and Albee[25]. Individual measurements were made on separate slag particles and the results averaged.

The results of the analyses are listed in Table II. They show that the slag compositions in the Marshall and Springfield samples are remarkably similar while the composition of the slag in the sample recovered from the Whitney Armory is distinctly different. This is taken to be confirmation that it was indeed Marshall iron that was in use at the Springfield Armory to make the Model 1855 rifle-musket barrel sampled.

Table II

Microprobe Analyses of Slag Inclusions %

	FeO	SiO_2	Al_2O_3	CaO	MgO	MnO	TiO_2	Na_2O	K_2O	P_2O_5	SO_3
Marshall Iron[a]	66.9	26.6	1.9	0.2	0.0	1.8	0.2	0.0	0.3	1.2	0.7
Springfield Barrel[b]	69.8	25.1	1.6	0.0	0.0	1.8	0.0	0.0	0.4	1.1	0.0
Whitney Barrel[c]	42.4	46.6	3.6	0.2	0.0	4.2	0.3	0.7	0.6	0.5	0.6

Notes

a. Sample from the Percy Collection, Science Museum, London.
b. From Model 1855 Rifle-musket made between 1859 and 1861.
c. Sample excavated at the site of the Whitney Armory.

The slag in the Marshall iron is very near to the composition of fayalite (71% FeO, 29% SiO_2). This means that the slag falls in the range of low liquidus temperatures, which should facilitate the mechanical working required to get a fine, uniform distribution of slag fibres in the finished iron. The phosphorus content is quite low; up to 10% P_2O_5 is commonly found in bloomery iron slag and Hedges and Salter report up to 20% in some of the currency bar slags they studied. Low phosphorus content is required if iron is to have good ductility.

The slag in the sample from the Whitney Armory site is well off the composition of fayalite, which would give it a higher liquidus temperature and perhaps make it more difficult to work the slag out of the iron bloom under the hammer. It is also distinguished from the Marshall iron by a relatively high manganese content. Some of the ores from the Salisbury District are rich in manganese[26]. Blast furnace smelting results in substantial transfer of Mn from the ore to the pig[27]. This Mn is largely taken up in the finery or puddling slag when the pig is converted to wrought iron[28]. We therefore expect to find it in the slag inclusions.

Discussions and Conclusions

The microstructural and chemical evidence confirms the inference from the Springfield Armory papers that it was Marshall's iron that was used in the barrel welding rolls at Springfield between 1859 and 1863. Although the number of cases studied so far is small, the results suggest that the methods described can be useful in determining the provenance of iron samples where the number of possible sources can be limited by historical or other data. It should, for example, be relatively easy to recognize the use of Marshall's iron in other weapons, either small arms or cannon.

The results obtained also help explain why Marshall's iron worked so well in the roll-welding machinery. Its homogeneity and the fine, uniform distribution of slag particles were particularly important. The relatively low liquidus temperature of the slag would also have facilitated welding. The low phosphorus content contributed to the good strength properties of the finished product. We infer that the roll-welding technique required skelps of unusually uniform quality and that an important part of the success of Marshall's iron in this application was due to the ability of the makers to supply a uniform product year after year. This accomplishment is the more remarkable when we remember that no methods of non-destructive testing of metals were available at that time. American ironmasters found the task of duplicating the Marshall iron a most difficult one.

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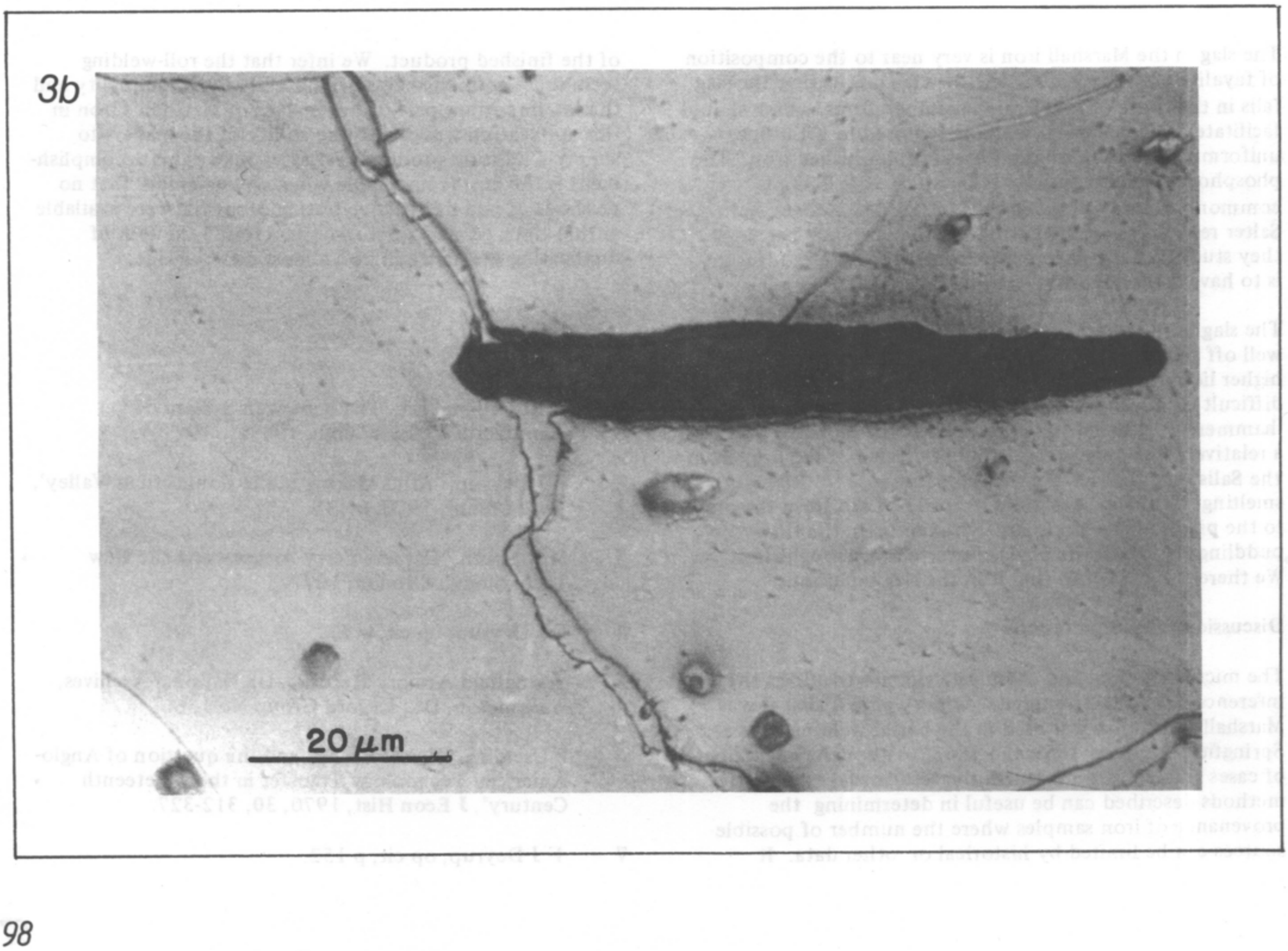

Depletion gilding and surface treatment of gold alloys from the Nariño area of ancient Colombia

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Introduction

The pre-Hispanic Indian cultures of the Colombian region of South America are well-known for their mastery of the art of lost-wax casting, for the fabrication of gold-copper alloys (which are often known as tumbaga alloys), and for the gilding of these alloys by surface enrichment techniques. There are many interesting and unusual features connected with the utilisation of gold in South America, especially in the production of gilded surfaces. Examples of some gilding techniques are: the electrochemical replacement plating of gold or silver on copper objects from the Mochica culture of Peru[1,2]; the depletion gilding of ternary gold-silver-copper alloys from the Chimu culture of Peru[3]; and the fusion-gilding of copper objects from the Esmeraldas district of Ecuador[4]. The present article examines some of the surface treatments which were in use by the Indians of the Narino area, in the southern highlands of Colombia.

Depletion Gilding

A widespread technology, particularly in the ancient Colombian region (which takes in present-day Panama and Costa Rica), was the gilding of gold-copper alloys by the removal of some of the surface copper, a process variously known as gilding, mise-en-couleur, surface enrichment, depletion gilding and colouring.

Lechtman[5] prefers the term depletion gilding to surface enrichment; she defines it as 'the enrichment of a surface in gold by the removal of other alloying elements already present'. There is some justification for this; surface enrichment is a process which can take place during burial of archaeological metals and can also be used in a more restrictive sense in the investigation of modern alloys which may show some elemental variation over the first few Angstroms of the surface[6].

Neither of these processes of surface enrichment is directly relevant to the discussion of gilding techniques employed by the ancient Indians, for here we are dealing with a deliberate enrichment technique which results in a gold-rich layer whose thickness can be measured in microns rather than Angstroms. The use of the word 'colouring' is not advisable since it is possible to make an object appear golden in colour by a variety of means, many of which are not metallurgical processes (such as the application of gold pigment). The older term 'mise-en-couleur' is sometimes used in the sense of 'colouration' and sometimes as 'surface enrichment'. Use of the term 'superficial parting' is also misleading if it is meant as a process distinct from surface enrichment, which it is not. It is better to use Lechtman's term 'depletion gilding', or 'surface enrichment'.

Examination of Some Colombian Tumbaga Alloys

Figures 1 and 2 show a complete object and some fragments of tumbaga alloy from the Narino area of Colombia. The disc shown in Figure 1 is in the collections of the Museo del Oro, Bogota (Museum No 21222); it was found in the Municipio of Pupiales, Department of Narino, in the Andean highlands north of the Ecuadorian border and is from the Piartal period, dating from about 800 AD to 1250 AD. This disc is made in a low gold content tumbaga (between about 15% to 25% gold by weight) which has been finished by depletion gilding and which shows a geometric design laid out over both surfaces in contrasting matt gold and burnished gold areas . The geometric design is matched on both sides and there is some evidence that discs like this were displayed by suspension on a cord attached to the central hole in the disc[8].

There are many examples from the Narino area of circular discs with geometric designs in contrasting surface colour or surface finish; for example, a disc illustrated by Plazas de Nieto[7] ,also from the municipio of Pupiales, shows a design combining the use of matt gold, burnished gold and copper-coloured areas. With the permission of the curatorial staff of the Museo del Oro, Bogota, some small fragments of gold and tumbaga were allowed to be taken to the Institute of Archaeology, University of London, for study by chemical and metallurgical means.

Figure 2 illustrates some of the fragments which were examined, including two pieces which show matt gold and burnished gold surfaces (numbers 2a and 2c). Number 2g is a fragment of a circular disc from the Municipio of Pupiales, and is typical of much of the metalwork from the Narino area. The disc has an estimated diameter of 110mm and the thickness of the fragment varies from 0.39mm – 0.41mm. A characteristic feature of these Narino tumbaga discs is that their thicknesses do not vary over wide limits; the surfaces have been smoothed and show no evidence of hammer marks. The careful control of the thickness of these sheet metal discs suggests the use of an abrasive finishing process to eliminate unevenness on hammering out the tumbaga ingot, for all of these Piartal period discs have been worked to shape rather than cast by the lost-wax process. Table 1 gives some analytical information for the objects shown in Figure 2; fragment 2g contains 15.3% gold, 80.5% copper and 2.6% silver (by weight), and the surfaces have been enriched in gold. They are a deep yellow colour with some purple-brown staining as a result of corrosion during burial. A small circular hole has been pierced through the disc, it shows some fine surface scratches following the circumference; these are probably a consequence of working the hole edge in which burred metal has been removed by an abrasive.

Figure 3 shows the microstructure of the fragment removed for examination. The tumbaga alloy has been worked to shape with small, twinned grains in which most of the twin lines appear straight, indicating that the final stage in the manufacturing process was an annealing operation. There are some cuprite inclusions in the metal, as well as cuprite lamellae running along the length of the section. Corrosion during burial results in the massive cuprite lamellae to be seen in the microstructure of many low-gold tumbaga alloys. The depletion gilded zone appears as a very thin gold rich layer on both sides of the section. The microstructure shown by this section is essentially that of a single-phased gold-silver-copper solid solution. Native gold was used in the ancient Colombian region without refining by cupellation or cementation, and so invariably contains a certain percentage of silver. The silver content of the native gold from Colombia may vary from approximately 0.1% to 40% silver,

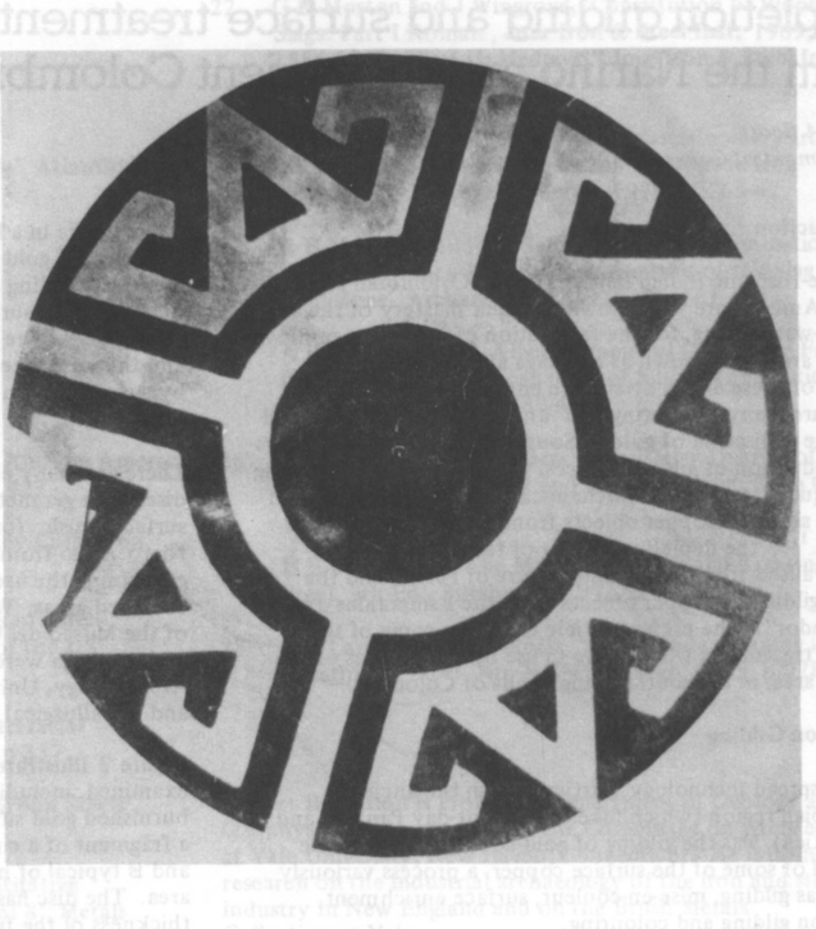


Figure 1
A complete tumbaga disc from the Municipio of Pupiales, Department of Narino, showing a geometric design in matt gold with a depletion gilded and burnished surround. The design is matched on both sides. Discs of this kind are typical of much Narino area metalwork of the Piartal period, dating roughly from 800 AD - 1250 AD. Diameter 150 mm.

although the typical range falls between 10% silver and 20% silver, corresponding to a Ag/Au ratio of 0.10 - 0.20. The majority of Colombian tumbaga alloys are therefore ternary alloys of gold, copper and silver[9]. It is useful to introduce here the factor f' as defined by McDonald and Sistare [10] which enables the equilibrium microstructure of a ternary gold-copper-silver alloy to be defined at a particular gold content in terms of the following ratio:

$$f' = \frac{\text{Ag wt\%}}{\text{Ag wt\%} + \text{Cu wt\%}} \times 100 \text{ -----(1)}$$

At particular gold contents therefore, the analytical data can be employed in equation (1) to determine whether the expected microstructure at equilibrium would be single-phased or two-phased, there being three basic micro-structural alloy types. In the case of the disc fragment 2g the factor f' gives a value of about 3 which places the alloy in the alpha (AuCuAg) solid solution region. This is, in fact, what we observe in the corroded microstructure shown in Figure 3.

An analytical investigation of several Colombian gold alloys was made using atomic absorption spectrophotometry, optical emission spectroscopy, scanning electron microscopy, optical metallography and electron probe microanalysis[9]. These Colombian gold alloys generally contained low levels of other metallic impurities which suggests that complex smelting operations were not carried out. In the case of the disc fragment examined here, fourteen trace elements were found (reported in parts per million w/w): Sb:20, As:50, B:1, Ca:10, Fe:30, Pb:10, Mg:3, Ni:50, P:500, Si:1000, Na:2, Sn:1, Pt:300, Mn:1.

The range of impurities and the amounts in which they are present in the disc represents quite a common picture as far as Colombian tumbaga alloys are concerned. Because of corrosion of these low-gold tumbaga alloys it is difficult to attach much significance to high levels of elements such as silicon and phosphorus. Platinum is usually only present in the ppm range in Colombian gold alloys, unless there is platinum present as a deliberate alloying addition [11,12].

Electron probe microanalysis was employed to take a number of spot analyses in a traverse across the polished metallurgical specimen; two line scans following this traverse are illustrated in Figures 4 and 5. Figure 4 shows the approximate position at which the spot analyses were obtained, indicated on the figure by numbers in square brackets, line scanning mode being used with the crystal spectrometers set for the analysis of gold and copper. The thin, gold enriched zone at the surface can be seen in Figures 4 and 5 and is some 3 - 5 microns in thickness. The line scans in Figure 5, which are for gold and silver, show that the small silver content of the tumbaga alloy is not removed from the immediate surface as a result of the gilding process used on the disc. The spot analyses gave the following results:

No.	Cu	Ag	Au	Total
1	80.5	2.6	15.3	98.4
2	80.6	2.6	17.1	100.3
3	55.3	3.9	22.2	81.4
4	44.9	6.4	25.6	77.2
5	38.7	6.5	47.8	94.4

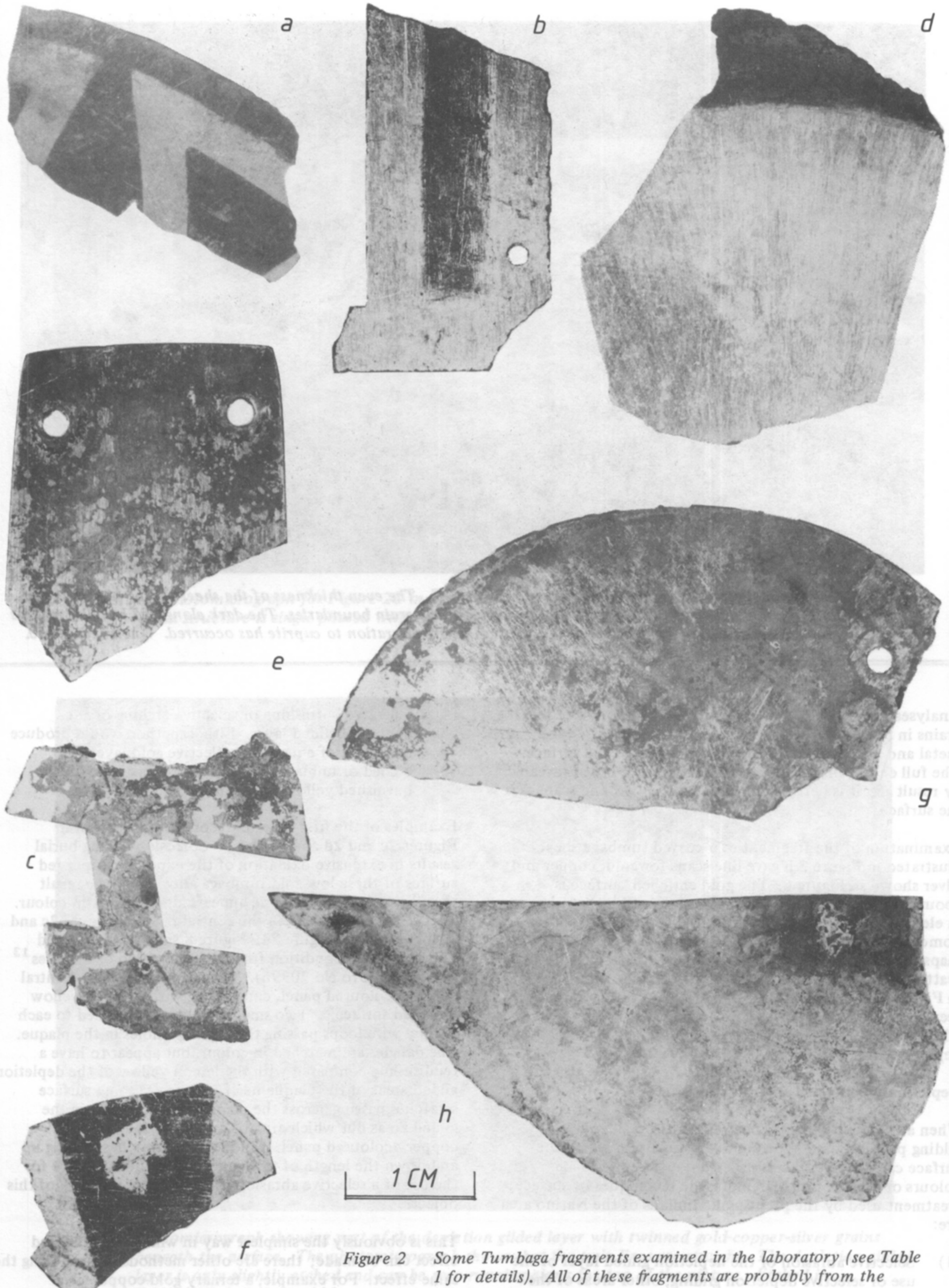


Figure 2 Some Tumbaga fragments examined in the laboratory (see Table 1 for details). All of these fragments are probably from the Piartal period.

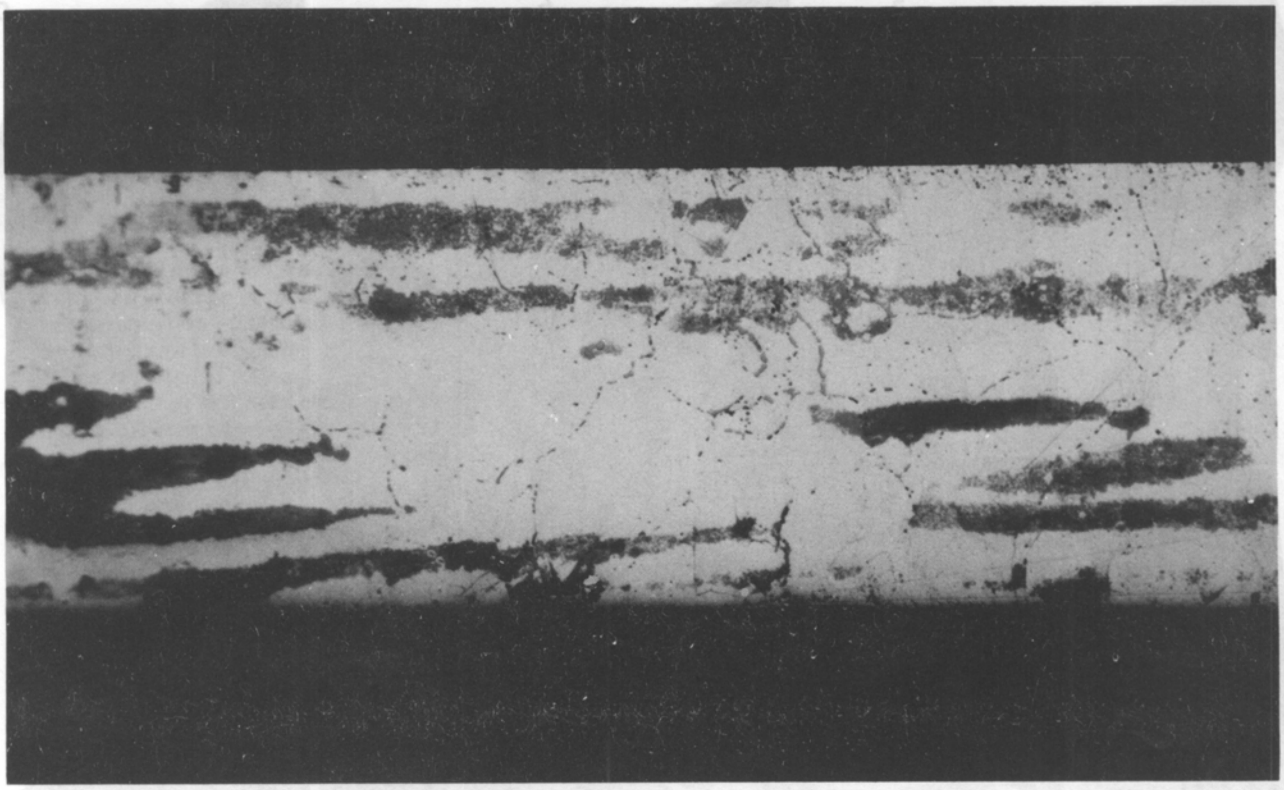


Figure 3A Photomicrograph of the fragment shown in Figure 2G. The even thickness of the sheet can be seen together with small globules of cuprite which follow some of the grain boundaries. The dark elongated lamellar regions are features resulting from subsequent corrosion where alteration to cuprite has occurred. Unetched. x150.

Analyses 1 and 2 were taken from sound, uncorroded metal grains in the alloy interior, result 3 is from an area of corroded metal and analyses 4 and 5 from the region of the surface. The full extent of surface enrichment in gold is not revealed by result 5; it is better illustrated by the two line scans across the surface.

Examination of the fragment of a curved tumbaga sheet illustrated in Figure 2 h gave line scans for gold, copper and silver shown in Figure 6. The gold enriched surface is about 5 microns thick and there is considerable disturbance in elemental composition beneath the surface before the homogeneous copper-rich interior is reached. Elemental maps for gold, silver and copper, together with a back-scattered electron image of the polished section are shown in Figure 7. The variation in element concentration can be seen to greatly increase the gold content of the surface, while leaving some silver and copper still present in the depletion gilded zone.

Depletion Gilding and Bi-Coloured Effects

When a tumbaga alloy has been finished by a depletion gilding process, there are a number of ways in which the surface can then be treated to create different surface colours or surface finish. Among the techniques of surface treatment used by the prehispanic Indians of the Narino area are:

(1) Selective abrasion of the depletion gilded layer or the use of selective depletion gilding, other areas of the surface masked off. Both these techniques would create a coppery-red surface contrasting with the golden depletion gilded layer.

(2) Selective burnishing or selective etching of the depletion gilded layer. Either method would produce the effect of a matt, unreflective gold layer (the etched or unburnished areas), contrasting with the burnished yellow of the depletion gilded layer.

Examples of the first type of decoration are shown in Figures 2c and 2d and Figure 8. Corrosion during burial results in extensive oxidation of the exposed copper-red surface of these low-gold tumbaga alloys with the result that this part of the surface appears almost black in colour. This effect can be seen in the central panel of Figure 2c and at the border of Figure 2d. Figure 8 shows a bicoloured plaque in good condition from the municipio of Pupiales[13] (Museo del Oro No 20996). This plaque displays a central coppery-coloured panel, contrasting with a lemon-yellow enriched surface. Two small dangles are attached to each side by wire loops passing through two holes in the plaque. The dangles are matched in colour, but appear to have a reddish hue compared with the lemon-yellow of the depletion gilded areas of the plaque itself. There are some surface scratches passing across the plaque, which appear in the gilded areas but which are not present in the central coppery-coloured panel. Fine surface scratches passing up and down the length of this panel are further evidence for the use of a selective abrasion process in the finishing of this object.

This is obviously the simplest way in which a bi-coloured effect can be made; there are other methods of producing the same effect. For example, a ternary gold-copper-silver alloy of composition 40% gold, 55% copper and 5% silver (weight%) was cast in the laboratory and worked into the shape of a small disc. The surface was cleaned and the central

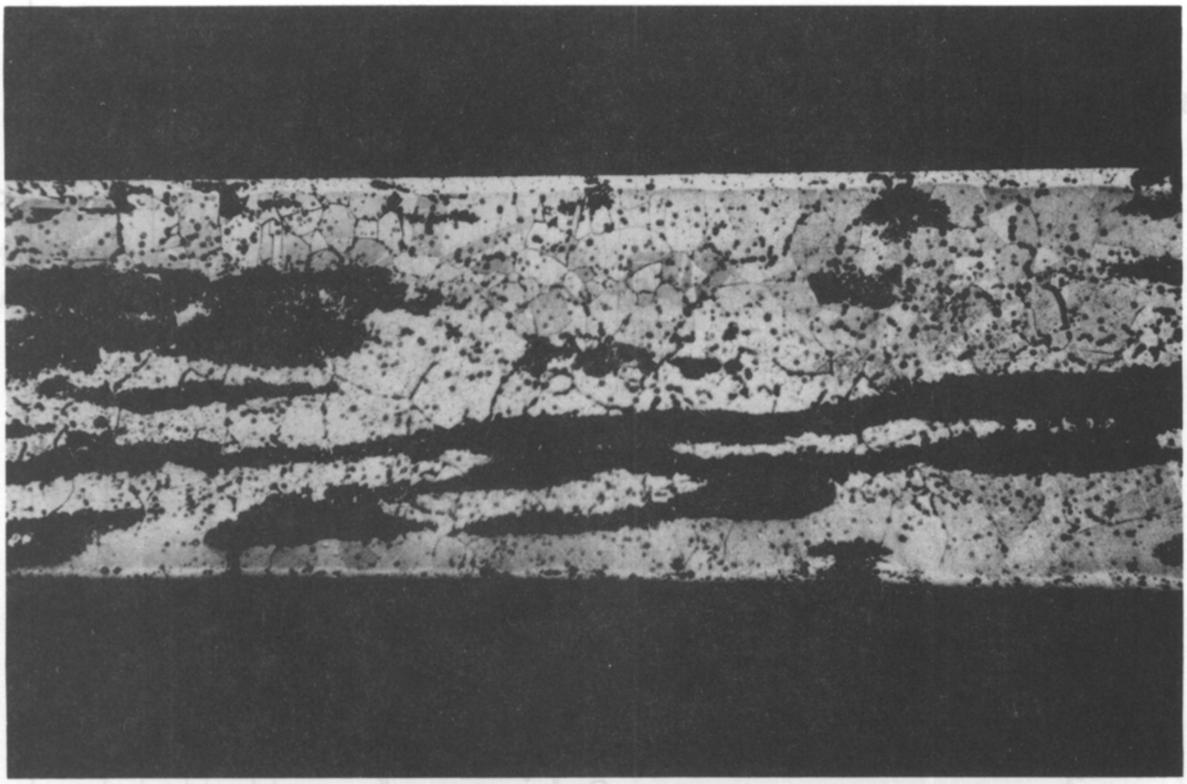


Figure 3B Etched photomicrograph for Figure 2G in which the enriched, depletion gilded surfaces can be clearly seen. The grain structure is single phased with twinned grains. Etched in KCN/ $(NH_4)_2S_2O_8$. x150.

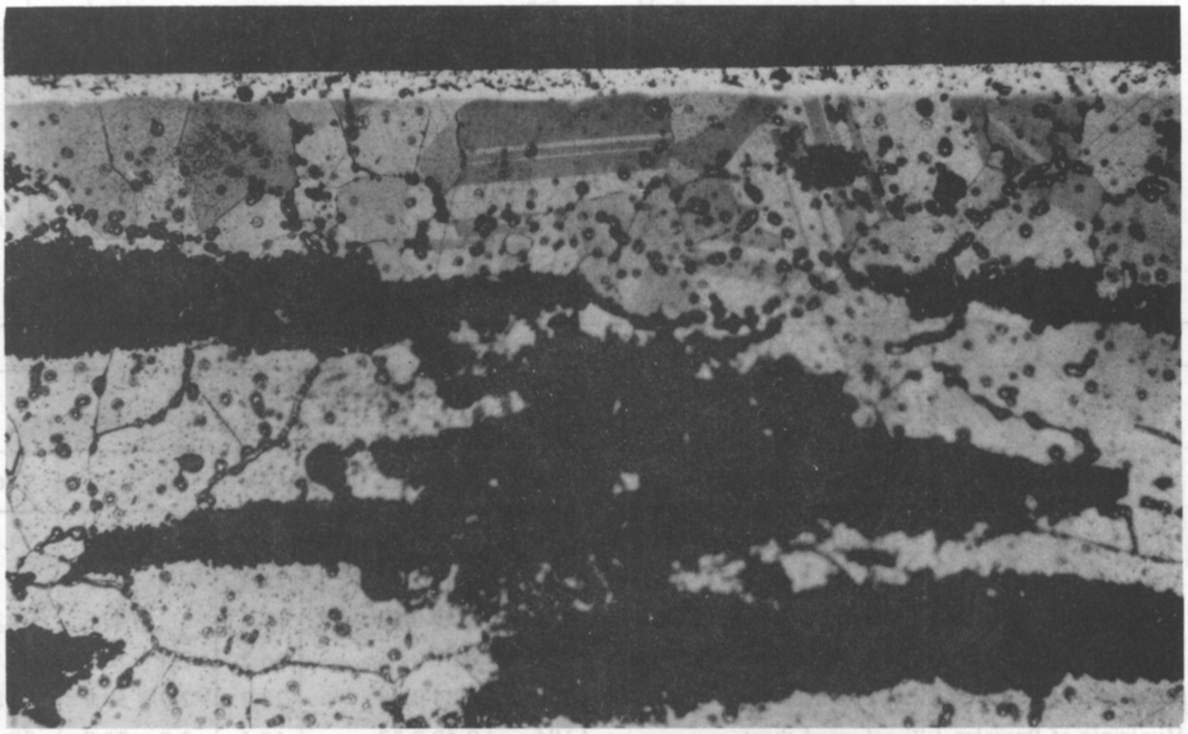


Figure 3C Photomicrograph showing part of the depletion gilded layer with twinned gold-copper-silver grains beneath the surface. The photomicrograph shows that the twin lines are straight. The depletion gilded layer is only slightly etched and can be seen running along the top of the picture. Etched in KCN/ $(NH_4)_2S_2O_8$. x300.

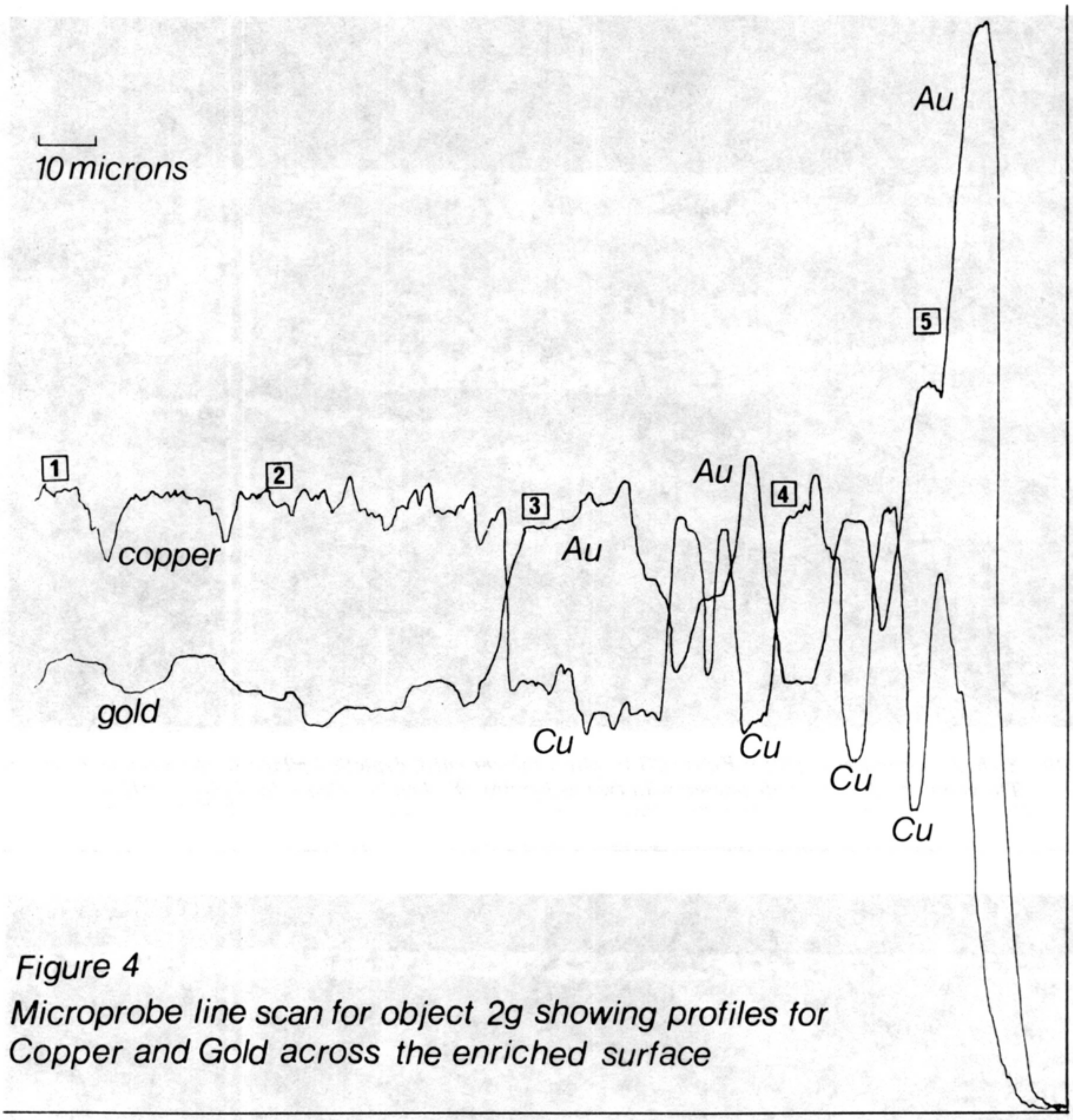


Figure 4
Microprobe line scan for object 2g showing profiles for Copper and Gold across the enriched surface

Table 1

Fig No	Provenance	Probable Nature of Fragment	Lab No	Thickness (mm)	Au	Ag	Cu	Total (%)
2a	Narino area	Bi-coloured disc fragment	149	0.32-0.35	24.9	4.1	65.6	94.6
2b	Municipio of Pupiales	Bi-coloured sheet fragment	134	0.32-0.34	21.4	2.4	58.3	82.1
2c	Municipio of Pupiales	Bi-coloured ornament fragment	136	0.39-0.42	17.8	3.2	49.8	70.8
2d	Municipio of Pupiales	Disc with bi-coloured surfaces	127	0.31-0.35	16.2	2.4	76.3	94.9
2e	Municipio of Pupiales	Part of a necklace plaque	132	0.33-0.39	22.2	2.7	59.9	84.8
2f	Municipio of Pupiales	Bi-coloured sheet	104	0.40-0.52	18.5	2.0	78.9	99.6
2g	Municipio of Pupiales	Part of a circular disc	130	0.39-0.41	15.3	2.6	80.5	98.4
2h	Municipio of Pupiales	Part of a curved sheet	139	0.32-0.74	14.9	3.3	73.9	92.1

Note: Methods of analysis used were atomic absorption spectrophotometry and electron probe microanalysis.

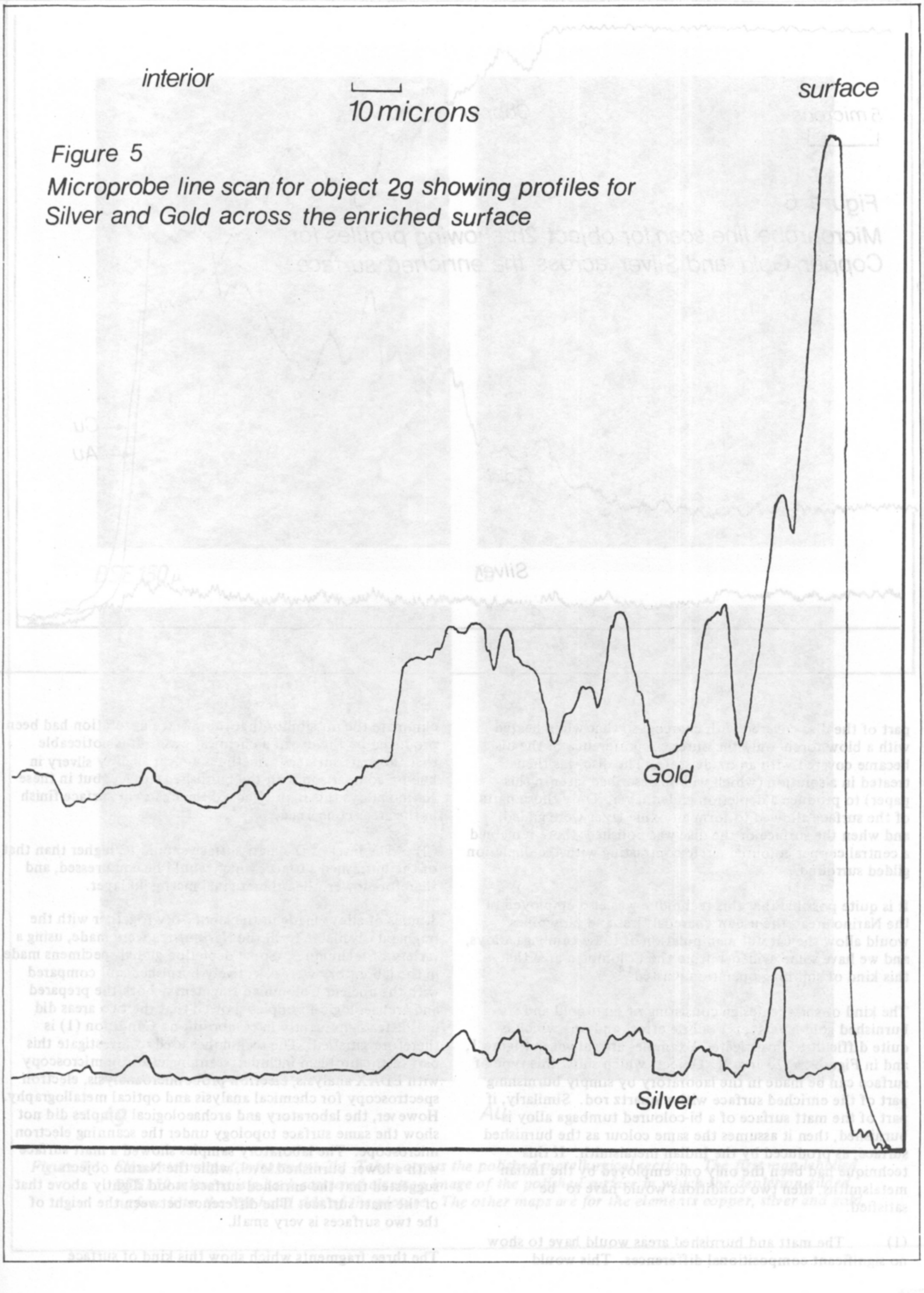


Figure 5

Microprobe line scan for object 2g showing profiles for Silver and Gold across the enriched surface

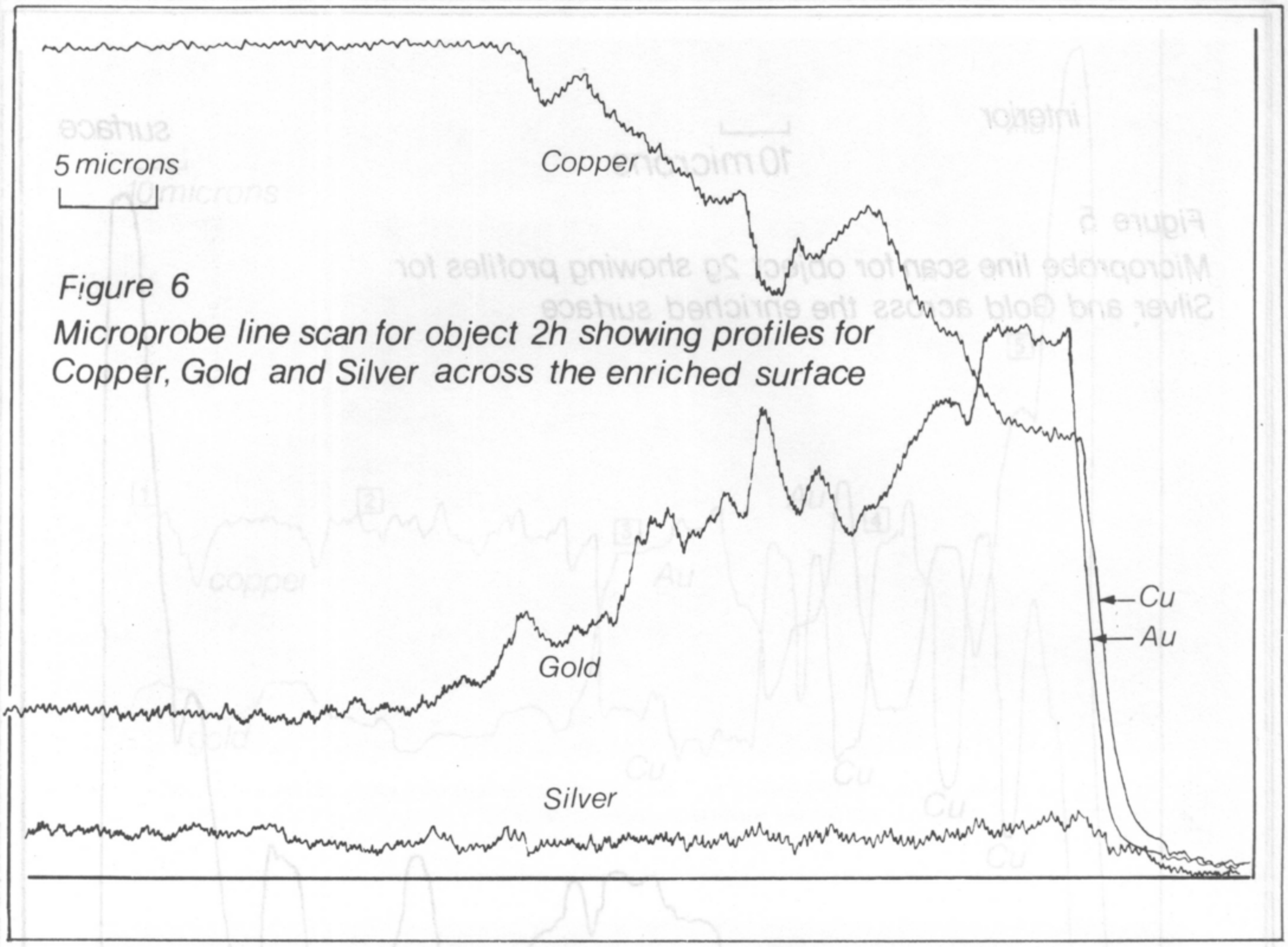


Figure 6
Microprobe line scan for object 2h showing profiles for Copper, Gold and Silver across the enriched surface

part of the disc covered with charcoal so that when heated with a blow torch, only the outer circumference of the disc became covered with an oxide scale. The disc was then treated in a solution (which will be described later in this paper) to produce a depletion gilded layer. Only those parts of the surface allowed to form an oxide layer were gilded, and when the surface of the disc was polished, there remained a central copper-coloured circle contrasting with the depletion gilded surround.

It is quite possible that this technique was also employed in the Narino area; the use of charcoal fires and blowpipes would allow the careful manipulation of these tumbaga alloys, and we have some evidence from the Colombian area that this kind of smithing operation existed[14].

The kind of surface design consisting of matt gold and burnished gold layers[2], is a subtle effect and one which is quite difficult to investigate. Examples are shown in Figure 1, and in Figure 2a, 2c and 2f. Objects which show this type of surface can be made in the laboratory by simply burnishing part of the enriched surface with a quartz rod. Similarly, if part of the matt surface of a bi-coloured tumbaga alloy is burnished, then it assumes the same colour as the burnished surface, as produced by the Indian metalsmith. If this technique had been the only one employed by the Indian metalsmiths, then two conditions would have to be satisfied:

(1) The matt and burnished areas would have to show no significant compositional differences. This would eliminate the possibility that the surface decoration had been produced by the use of a chemical wash. It is noticeable that the matt surfaces sometimes appear slightly silvery in hue by comparison with the burnished surface, but in these Narino alloys this is an effect of the different surface finish in the areas concerned.

(2) The level of the matt surface should be higher than that of the burnished surface, which would be compressed, and therefore lower, then the original matt gold layer.

Studies of alloys made in the laboratory together with the fragments available from the Narino area were made, using a variety of techniques. Some depletion gilded specimens made in the laboratory were selectively burnished and compared with the ancient Colombian fragments; both the prepared and archaeological samples showed that the two areas did not differ significantly in composition. Condition (1) is therefore satisfied. The techniques used to investigate this part of the problem include; scanning electron microscopy with EDAX analysis, electron probe microanalysis, electron spectroscopy for chemical analysis and optical metallography. However, the laboratory and archaeological samples did not show the same surface topology under the scanning electron microscope. The laboratory samples showed a matt surface with a lower burnished level, while the Narino objects suggested that the enriched surface stood slightly above that of the matt surface. The difference between the height of the two surfaces is very small.

The three fragments which show this kind of surface

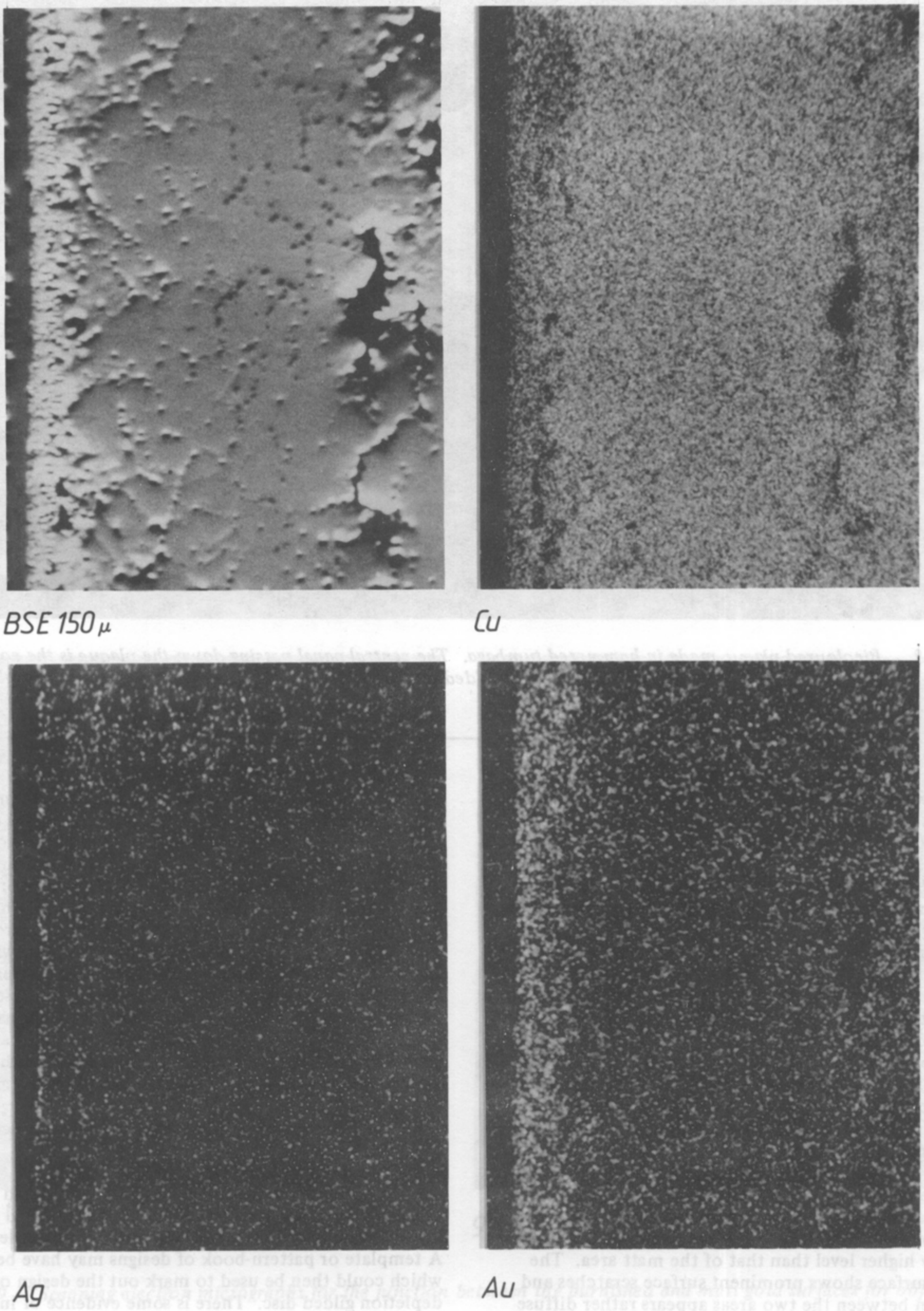


Figure 7 Elemental maps for fragment 2h. Taken across the polished metallurgical section. The first map labelled BSE150 microns is a back-scattered electron image of the polished surface in which the depletion gilded surface is to the left-hand side of the picture. The other maps are for the elements copper, silver and gold.

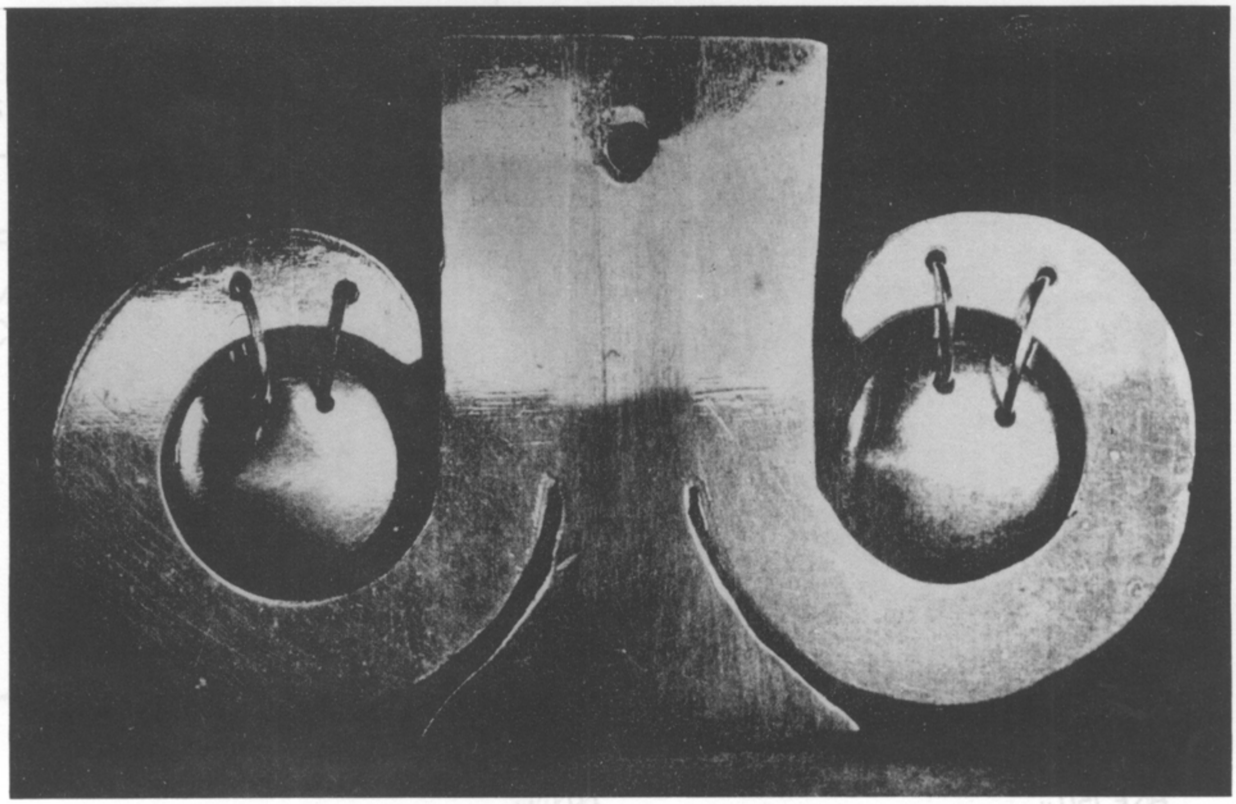


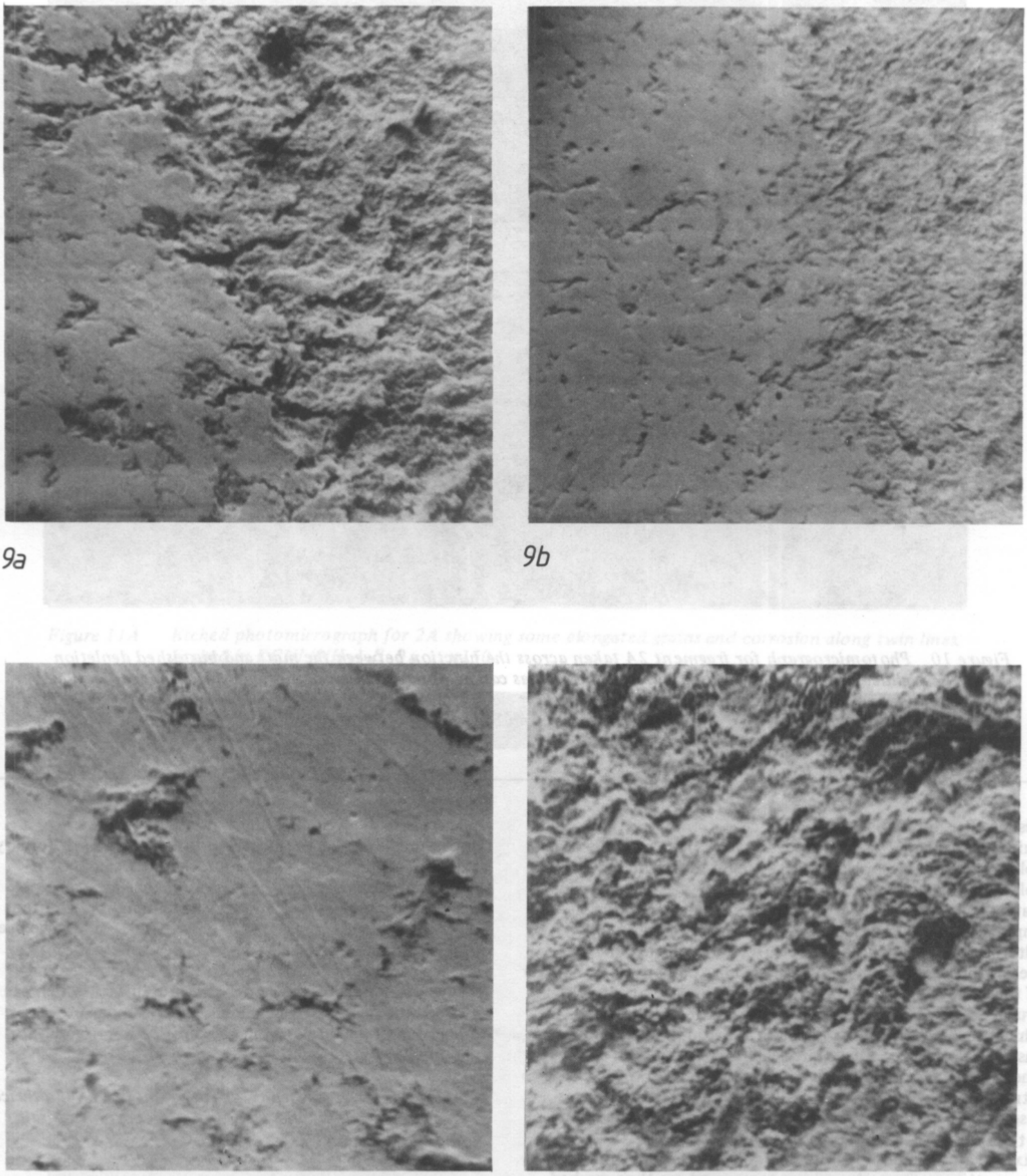
Figure 8 Bicoloured plaque made in hammered tumbaga. The central panel passing down the plaque is the copper-colour of the tumbaga alloy with depletion gilded surround. From the Municipio of Pupiales, Piartal period width of the plaque 62 mm.

illustrated in Figure 2 (a , c and f), were examined in detail. Figure 2a is a disc fragment of estimated diameter 120mm, made in a tumbaga alloy of composition 24.9% gold, 4.1% silver and about 68% copper. There is a matched geometrical design on both sides of the fragment in which a narrow strip of matt gold contrasts with a background of burnished gold. The design is rather similar to that of the complete disc shown in Figure 1. The microstructure of a section taken across the two surfaces can be seen in Figures 10 and 11; it is a typical copper-rich tumbaga alloy section, in which lamellae of cuprite corrosion pass along the length of the section. The microstructure shows that the disc has been worked to shape with cycles of cold-working and annealing; the surfaces are enriched on both sides, but no difference can be seen in section (or in a taper section), between areas which, on the surface, are matt and polished in appearance.

The surface of the disc was examined directly using the metallurgical microscope. At high magnification some islands of burnished metal can be seen in the matt area, and at a slightly higher level than that of the matt area. The burnished surface shows prominent surface scratches and the junction between the two areas appears rather diffuse and ill-defined. One scratch passes along the burnished area and appears to continue across an island of burnished metal in the matt area. The existence of these islands of polished surface in the matt area suggests that the method used to create the bi-coloured surface was an etching process which removed a very thin layer of the polished surface over selected regions of the disc.

The fragment illustrated in Figure 2c, is part of a nose-ornament or plaque also from the municipio of Pupiales and of the Piartal period. The bicoloured surface is similar to that shown by Figure 2a; it has a matt gold and polished gold design, partially obscured by secondary copper corrosion products. Some areas are free of surface corrosion and one such area was examined by scanning electron microscopy. The results are shown in Figure 9. Figure 9b shows the two surfaces at low magnification, the junction between them again appears quite diffuse. At x280 (Fig 9a), a clearer view of the junction between the two surfaces is obtainable. The burnished surface shows a number of small surface irregularities, together with some fine scratches which stop abruptly at the edge of the burnished layer. The matt surface is at a lower level than that of the burnished layer; it has a pitted, uneven surface which is typical of a chemically etched topography.

These Colombian depletion gilded and bi-coloured discs, such as the example illustrated in Figure 1, have etched surface designs which have been laid out with considerable accuracy. A template or pattern-book of designs may have been made which could then be used to mark out the design on the depletion gilded disc. There is some evidence of incised lines or scratches in the surface along the boundary between the matt gold and polished gold areas in a few fragments examined. The examination has found no evidence for the addition of any further metallic coating, or for the painting on of metallic salts followed by a re-firing process. The already burnished surface must be stopped-off, leaving exposed the areas which will become the matt gold



9a 9b 9c 9d

Figure 9 Scanning electron micrographs for the junction between the burnished and matt gold surfaces for object 2e. Figure 9A (x280) shows a detail of part of the two areas. The pitted nature of the matt surface can be clearly seen as well as surface depressions in the burnished zone. Figure 9B (x140) presents more of an overall view of the junction in which less detail is visible, although more of the burnished layer can be observed. Figure 9C (x680) shows surface detail of the burnished layer and figure 9D (x680) detail of the matt layer.

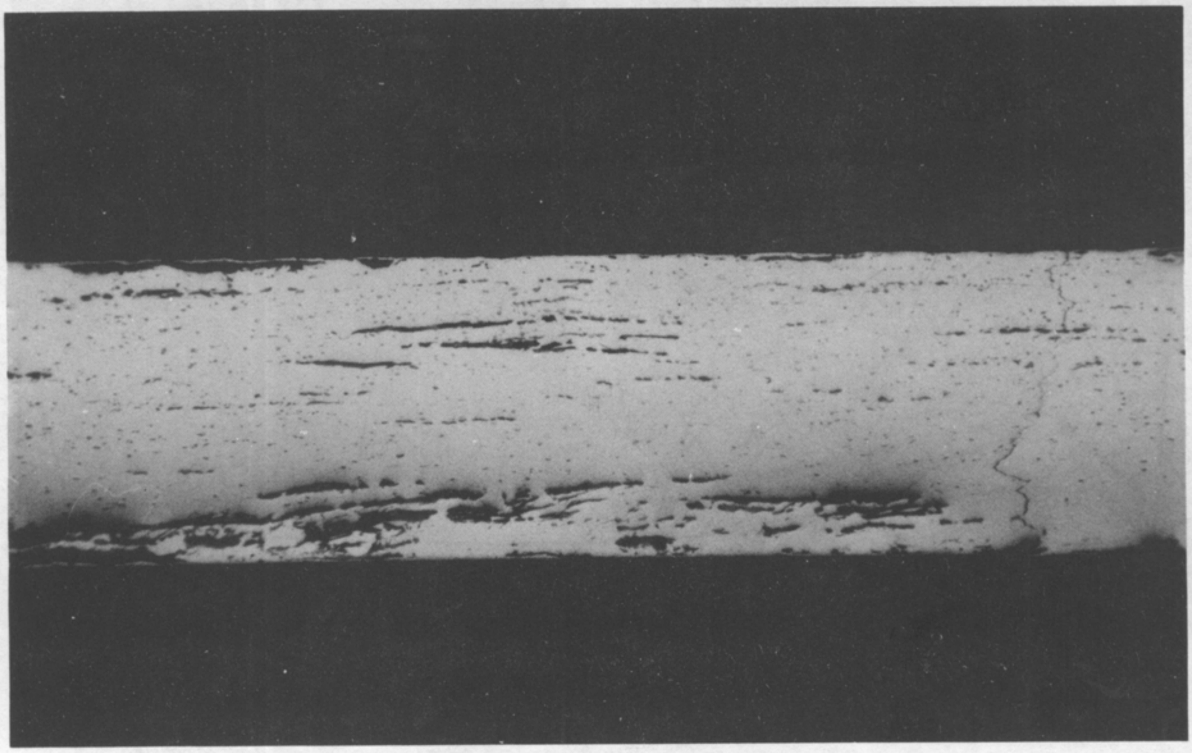


Figure 10 Photomicrograph for fragment 2A taken across the junction between the matt and burnished depletion gilded areas. No difference between these areas can be observed in section even at higher magnification. The section shows some cuprite corrosion, especially beneath the gilded surface to the top left-hand side of the picture. A typical crack across the alloy can be seen to the right-hand side, typical of stress corrosion cracking. Unetched x150.

design. It is interesting to note in this connection that quite recent technological processes have been employed on gold or gold plated objects with the aim of producing matt gold and polished gold designs. Gowland[15], for example, states that such effects are generally made by masking the unpolished gold and polishing the unmasked areas. Alternatively, the whole of the surface is polished and the areas which are to remain bright are masked and the remainder of the surface is either blasted with an abrasive or scratch brushed. Gowland also mentions an etching process in which the areas to be left polished are stopped-off with a paste of 10 parts chalk, 1 part sugar and 1 part gum arabic. The matting agent is prepared from 8 parts of sodium nitrate, 5 parts of salt and 7 parts of alum. The mixture is fused together, cooled, and ground in a mortar. The object is then carefully heated on a hot plate, covered with the mixture and heated until the powder fuses and re-solidifies. The matting agent and masking compound are then washed away in water. It is quite possible that a similar process was used by the Colombian Indians to create their etched gold designs.

Ethnohistorical and Chemical Evidence for Depletion Gilding

The fragments examined in this paper show that a thin surface enriched gold layer was produced over low-gold content tumbaga alloys. What are the possible techniques which could have been employed to produce this gilded layer? Lechtman[3] has examined some Chimu and Moche metal objects from Peru which were found to have been finished by a depletion gilding process, in which both copper and silver were removed from the surfaces of ternary gold-silver-copper alloys, containing high percentages of silver (approximately 15 to 45% Ag). Lechtman[3] and Smith[16] have suggested that corrosive mineral preparations based on copiapite, $Fe_3(SO_4)_4(OH).13H_20$, could have been employed, mixed with salt to produce a cementation mixture capable of removing both silver and copper and leaving a thin porous layer of gold at the surface which can then be burnished to give a gilded layer. Similar processes were used in the Old World in the purification of gold, for example Pliny states[17]

> *'the gold is heated with twice its weight of salt and thrice its weight of misy, and again with two portions of salt and one of schist . . .'*

Percy[18] states that this is a process using native yellow copperas, that is, copiapite; the same substance suggested by Lechtman. Strabo mentions the use of an 'alum' of some kind in the removal of silver from electrum and Beckman[19] maintained that this substance was ferrous sulphate, $FeSO_4.7H_20$, which Smith[16] also thinks is the mineral described by Theophilus in his gilding recipes. Important historical information relating to the New World is given by a few writers at the time of the Spanish Conquest; among the most relevant are the following quotations. For example, Bernardino de Sahagun[20], writing in 1565 of Aztec technology records:

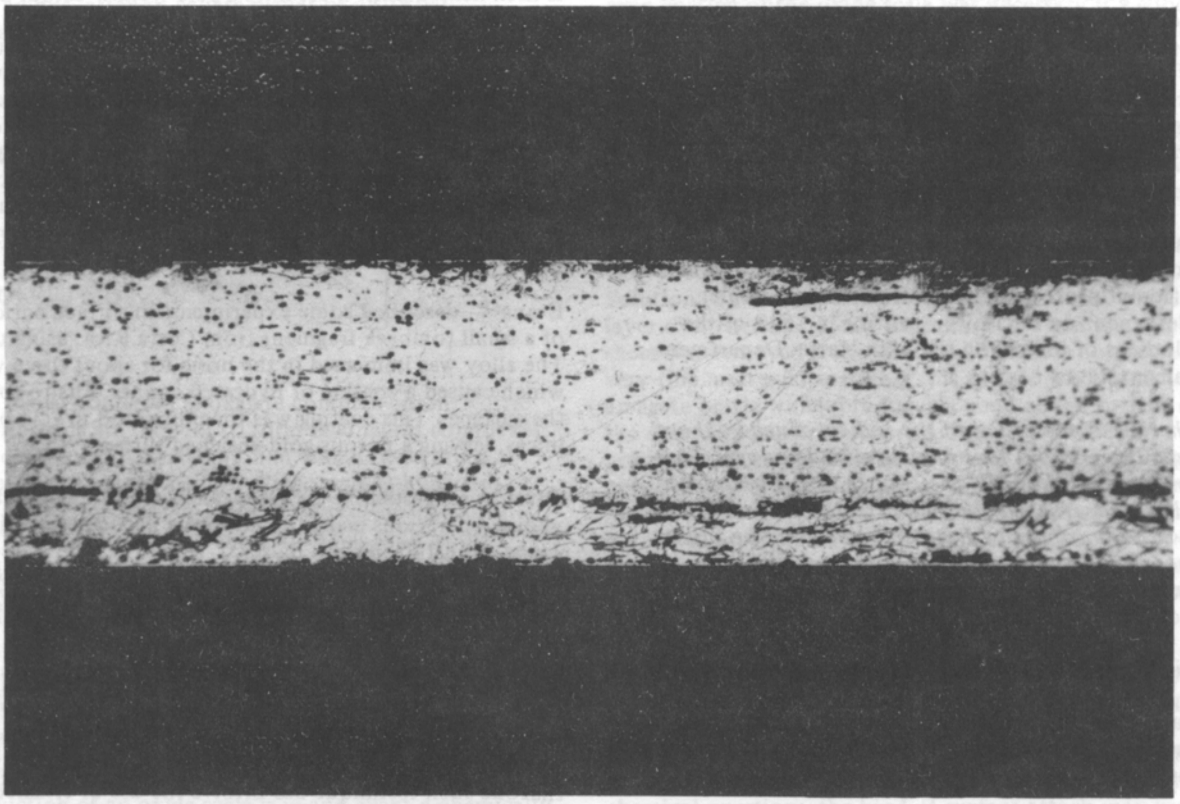


Figure 11A Etched photomicrograph for 2A showing some elongated grains and corrosion along twin lines. Etched in $KCN/(NH_4)_2S_2O_8$ x150.

Figure 11B Etched photomicrograph for 2A showing the depletion gilded surfaces. Note that the small crack in the surface at the bottom centre is also gilded along its length. Etched in $FeCl_3/HCl$ x300.

> *'it was in addition treated with alum; the alum with which the gold was washed and rubbed was ground. A second time it entered the fire; it was heated over it. And when it came forth once more, for the second time, it was once washed, rubbed with what was called 'gold medicine'. It was just like yellow earth mixed with a little salt; with this the gold was perfected; with this it became very yellow . . .'*
>
> (Fray Bernardino de Sahagun 1565).

The ethnohistorical accounts, dating from the time of the Spanish contact with the ancient Colombian Indians, mention rather different processes in operation. For example, Martin Fernandez de Enciso [21], writing in 1519 of the Tairona Indians of the region of Santa Marta, Department of Magdalena, states:

> *'. . . there is in possession of the Indians much gold and copper. There is also found much gilded copper. The Indians say that they gild the copper with a herb that is in that land, crushed, and with the top taken off; and they wash the copper with it; and placed in the fire it assumes the colour of very fine gold, and changes in colour more or less according to whether they give it more or less of the herb . . .'*
>
> (Martin Fernandez de Enciso 1519).

There is an interesting sixteenth century document from Tamalameque[22], in lowland Colombia, which describes the process as follows:

> *'. . . and in this way, placing it (a bracelet) in the fire, taking it out and putting it in water and hammering it on an anvil with the stones described they worked until they had increased its size many times until it was finished and then the herb they brought to give it colour was crushed on a stone and, once crushed in this way, they placed it in a small pot which they brought in and added water and ground white salt and stirred all together (then they polished, heated, and quenched it in the solution several times) . . . and in this way it attained the colour and finish it should have . . . and they cleaned the said manylla (bracelet) with small quantities of fine sand that they brought in a maize husk, with their hands and water . . .'*
>
> (Tamalameque 1555).

It is of interest, in connection with the descriptions from Colombia, that Rivet and Arsandaux [23] state that the Ecuadorian Indians at that time were using the juice of the plant **Oxalis pubescens** to gild tumbaga alloys. Stone and Balser [24] described some experimental work in the gilding of a tumbaga alloy using the juice of the plant **Oxalis vulcanicola**. They immersed the tumbaga in the crushed plant juice for about three weeks, which produced a dark skin over the alloy. This was then heated with a blowpipe and allowed to cool. A gold enriched surface became visible after cleaning the tumbaga alloy in a dilute solution of sodium bicarbonate.

Friedemann[25] observed surface enrichment techniques among the present-day Negro goldsmiths of the region of Barbacoas, in the lowland area of the Department of Narino. The tumbaga alloy was first heated in the open air to oxidise some of the surface copper, followed by boiling in a clay jar with a mixture of 25% alumbre (alum; potassium aluminium sulphate $K_2SO_4.Al_2(SO_4)_3.24\ H_2O$), 50% sal de nitro (sodium nitrate, $NaNO_3$), and 25% of salt (NaCl) dissolved in water to make a thin paste. The paste is poured into the jar and the object immersed. The mixture is then heated until it assumes a pale yellow colour and becomes thick. Water is then added and the mixture boiled until most of the water has evaporated. The tumbaga alloy now has an enriched gold surface and it is removed from the solution rinsed in lemon juice and the surface polished. This particular recipe is essentially the same as that used by Lechtman[1] and by Lechtman, Erlij and Barry[2], to deposit very thin gold films by electrochemical replacement from solution onto cleaned copper sheet. This unusual technique of gilding was probably the method used by the Moche metalsmiths.

Evans[26], described some experiments in surface enrichment of a small tumbaga fragment from Costa Rica, using urine. The alloy was immersed in the urine for about three weeks which caused a coating of hydrated copper salts to form on the surface. This coating was then dissolved in acid plant juices, leaving a porous gold-enriched surface.

Rivet[27] suggests that the Oaxacans were carrying out gilding operations using the juice of a particular species of **Liana**, whilst Stone and Balser [24] think that the Aztecs could have used **Mansteras** and **Anthuriums**, both of which have a high acid content, mostly in the form of oxalic acid.

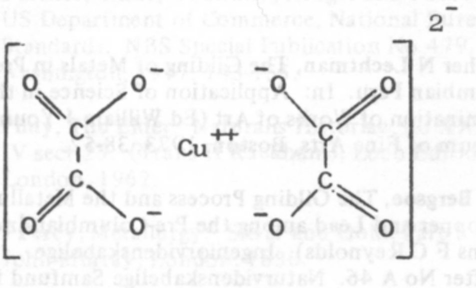
There is, then, a lack of precise information concerning the plants which the ancient Colombian Indians were apparently using for their depletion gilding, as well as a number of possible alternative processes. But we do know that one such technique did involve the use of crushed plant extracts. The function of these plant juices is essentially to dissolve some of the copper content of the tumbaga alloy surface, and to leave behind the gold as a thin porous layer. Plants of the **Oxalis** genus have been suggested and could certainly have been used in the Narino highlands as many of the species grow well at high altitudes. There are also some modern references to the use of these plants for the cleaning of metals: Grieve [28] mentions the use of **Oxalis acetosella** in Europe, Peckholt [29] the use of **Oxalid decipiens** and **Oxalis martiana** in Brazil, and Rivet and Arsandaux [23] **Oxalis pubescens** (Chulco) in Ecuador.

The **Oxalis** genus is a large one, with over 1,600 members of which some 400 are to be found in Colombia alone [30,31,32].

The **Oxalidaceae** can be divided chemically into three categories:

(1) Rich in tannins, oxalate absent
(2) Rich in oxalates, tannins absent
(3) Both soluble oxalates and tannins present

The common constituents of these plants are: oxalid acid, $(COOH)_2$; acid potassium oxalate, COOH.COOK, 'salts of lemon' potassium quadroxalate $(COOH)_2.COOH.COOK.2H_2O$, tartaric acid (de-hydroxysuccinic acid CHOH.COOH.CHOH.COOH) and tannic acids (which are complex combinations of glucose and gallic acids). The fact that both Fernandez de Enciso and the Tamalameque document mention that the plant was crushed before water was added is of some interest. The maceration of the plant tissues would assist in breaking down the cell walls, thus releasing the active chemical constituents which could then be solubilised in water. If the plants had been cut up into pieces rather than crushed, then the efficacy of the solution would be diminished. Regardless of the exact identity of the plants used by the Colombian Indians, the chemistry of the process is fundamentally the same: copper must be removed from the immediate surface of the tumbaga alloy. Copper is dissolved by organic acids such as acetic, citric, malic, tartaric and oxalic by the formation of soluble complex anions, often of square planar or distorted octahedral geometry. Oxalid acid for example gives:



A square planar copper (11) oxalate complex anion. Citric and tartaric acids are thought to form octahedral complexes, as in the copper (11) citrate anion in which two citrate groups act as terdentate ligands. Citric acid (2-hydroxypropane-1:2:3-tricarboxylic acid) occurs to the extent of 6% to 10% in the juice of unripe citrus fruit such as the lemon; a plant mentioned by Friedemann[25] as being used by the Negro goldsmiths of the Mompos region of Colombia for the cleaning of tumbaga alloys.

The Tamalameque document states that the object to be gilded was heated and quenched in the solution several times. Not only would heating result in the formation of copper oxide scale on the object, but such scale must be formed by the working and annealing of these copper-gold alloys. The production of an oxide scale is in any event a chemically sound preliminary step before using plant acids to carry out the gilding process. This is because weak organic acids are much more effective in complexing with cuprous or cupric ions than they are with copper itself.

In order to study the efficacy of some simple organic acids in producing a gilded layer over a tumbaga alloy, some laboratory experiments were carried out. A ternary gold-copper-silver alloy of composition 40% gold, 55% copper and 5% silver was cast in a graphite crucible at 1150°C with the surface of the alloy covered with powdered charcoal. This is a type 1 alloy (see McDonald and Sistare[10], alpha (AuCuAg) bordering on type 2 alpha (AuCuAg) + alpha' (AgAu). It is expected to be moderately soft and to have only slight age-hardening properties. That the alloy may harden slightly on air-cooling was shown by a series of microhardness tests on the as-cast air-cooled ingot, and on an annealed slice cut from the same ingot. The air-cooled ingot gave an average of 60HV and the annealed slice an average of 49HV (annealing was carried out at 700°C for 60 minutes followed by quenching in water). The alloy has a liquidus of about 950°C. It was subjected to a series of working and annealing operations; hammering was carried out in the cold state using a percussion mortar and the specimen annealed at 600 - 700°C for 5-10 minutes followed by quenching in water. An 80% reduction in thickness was obtained and the resulting sheet cleaned by rubbing on fine silicon carbide paper. The sheet was now cut into a number of slices to carry out different surface treatments. By placing the unprotected sheet in the furnace for a few minutes at 600 - 700°C, a fine scale of copper oxides formed. A number of different solutions were now made up to study the effects on the alloy surface and on the oxide layer:

(1) 10% oxalic acid in distilled water
(2) 10% oxalic acid + 10% sodium chloride
(3) 10% citric acid
(4) 10% citric acid + 10% sodium chloride
(5) 5% potassium cyanide

The results of this series of experiments showed that a final, even coating of the oxide scale was necessary if a good surface-enriched gold layer was to be formed using the solutions listed. The tumbaga slice was immersed in the solution and heated until gentle boiling occurred and left for about 20 - 30 minutes. Following this procedure, it was found that the best surface-enriched layer formed using solution (2). Solution (1) was not very effective in producing a gold-rich layer; solutions (3) and (4) were found to be satisfactory, but both had a tendency to produce a layer of re-deposited copper, which interfered with the production of a uniform gold enriched layer. Solution (5) was not effective in removal of the oxide layer over the time of the experiment. When the tumbaga sheet was removed from solution (2), it was covered with a very fine matt gold surface. This surface was burnished with an agate pestle which produced a good gilded surface over the sheet. Electron microprobe line scan studies on a polished section of this sheet showed enrichment in gold over 3-5 microns at the surface. There was still evidence for the existence of some silver and a little copper in this burnished layer. This kind of gilded layer closely reproduces that found on ancient Colombian tumbaga alloys, including the pieces from the Narino area reported in this paper.

A great deal of fundamental work concerning the way in which enriched gold layers form on gold-copper and gold-silver alloys has been carried out which cannot be reviewed in detail here[33, 34, 35, 36, 37, 38]. The mechanism by which gold-enriched layers form is a complex electrochemical question; the kind of surface attack may vary considerably depending on the corrosive agents employed. Pickering and Swann[33] for example, studied the effects of a dilute ferric chloride solution; a reagent similar to the corrosive mineral preparations which might utilise copiapite and salt.

Pickering and Swann used a 86% copper 14% gold alloy in their experiments and found that both dilute aqua regia and ferric chloride produced small pits which grew to about 50-100 Å in diameter; The whole surface eventually being covered in corrosion pits. A strong epitaxial relationship existed between the gold-rich surface and the alloy interior. With a solution of potassium cyanide however, the surface attack was quite different; no small pits formed and instead the surface became covered with shallow depressions. The maximum depth of these depressions was about 900Å and the average diameter 3600 Å. In sodium chloride solutions it is possible that there is some corrosion and redeposition of the gold at the immediate surface. Tissot, Luthy and Monnier[39] studied the effects of a 0.6 Molar solution on the anodic dissolution of a gold-copper alloy (75 wt% gold 25% copper). They observed some dissolution and surface enrichment over about 5 microns and detected three zones by use of the electron microprobe; a region of external porosity, a region of internal compact metal, slightly enriched in gold, and the bulk of the unattacked base gold. They suggested the following formulae as the mechanism of the dissolution-redeposition reaction:

$$\mathrm{Cu + 2Cl} = (\mathrm{CuCl_2})^- + e^-$$

$$\mathrm{Au + 4Cl} = (\mathrm{AuCl_4})^- + 3e^-$$

$$(\mathrm{AuCl_4})^- + 3\,(\mathrm{CuCl_2})^- = \mathrm{Au} + 3\mathrm{Cu}^{++} + 10\mathrm{Cl}^-$$

The corrosion of gold in acidified sodium chloride solutions has been extensively investigated[40]. It is thought that both Au (1) and Au (111) take part in the corrosion reaction; the products are cathodic to copper, and therefore liable to be redeposited in gold copper alloys.

There are a number of interesting points which emerge from this brief review; firstly, that the investigation of the corrosion micromorphology of a depletion gilded layer may itself provide some clues as to the nature of the corrosive reagents employed by the ancient Indians; if, for example, differentation could be made by the use of the transmission electron microscope, it may be possible to distinguish between corrosion pits and channels on a well-preserved matt gilded layer and to correlate the structure with samples studied in the laboratory; this is currently being investigated. The second point is that the document from Tamalameque specifically mentions the addition of ground white salt to the reaction mixture, which is chemically well-founded. It is exactly this type of organic acid and salt combination that the laboratory studies showed was very effective in producing a depletion gilded layer on the tumbaga alloy studied. The gilding process was also convenient and took a matter of minutes; unlike the three week long process described by Stone and Balser[24] or by Evans[26].

Although corrosive mineral preparations based on ferric salts may well have been used, the evidence suggests that they would not have been necessary for the depletion gilding of Colombian tumbaga alloys. Since the Peruvian alloys mentioned previously often have a high silver content, it may well have been necessary to employ a different technique of surface enrichment than that which appears most likely for the Colombian region. There may be a diversity of technique here rather than a diversity of metallurgical practice– the aim, to create a golden surface over an alloy containing low percentages of gold – remains the same.

Whatever the exact nature of the depletion gilding process was, the Indians of the Narino area of Colombia have shown themselves to be skilled and subtle craftsmen who appreciated the decorative possibilities of these gold-copper alloys in ways not yet recorded elsewhere, and who devised techniques of surface treatment which appear to be uniquely South American.

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A rock-cut copper smelting furnace in the Timna Valley

Beno Rothenberg

The very first excavation in the Timna Valley (South Israel), took place in 1964 at the Late Bronze Age Site, No 2 (Fig 1) and several copper smelting furnaces with sophisticated slag tapping facilities were discovered.[1] Three furnaces were located next to heaps of circular tap-slag, all showing a cast-in hole in the centre. During recent work on the final excavation report on the Arabah excavations 1964-1979, some questions arose concerning the accurate stratigraphic connection of the tapping furnaces of Site No 2 with clay tuyeres collected at the site during surveys and excavations.[2,3] It was therefore decided to excavate a small slag heap of tap slag (Area Z) located on the slopes of a barren hill, separated from the main smelting site by a narrow sandy wadi (Fig 2). Here a slagged furnace wall fragment, only about 20 cm long, but apparently in situ, had previously been noticed by us among stone debris and slag, sticking out of the ground almost at the level of bedrock.

During a short season of excavations in December 1982, a small square, 1.5 x 2.0 m, was excavated with the 'furnace wall fragment' in its centre (Z/b), and a trial trench, about 7 m long and 1.0-1.5 m wide, was dug from this square to and through the adjacent slag heap (Z/d Fig 3). There can be no doubt about the stratigraphic connection between this slag heap of circular slag, each with a cast-in hole in the centre, and the copper smelting furnace uncovered in the excavated Square Z/b.

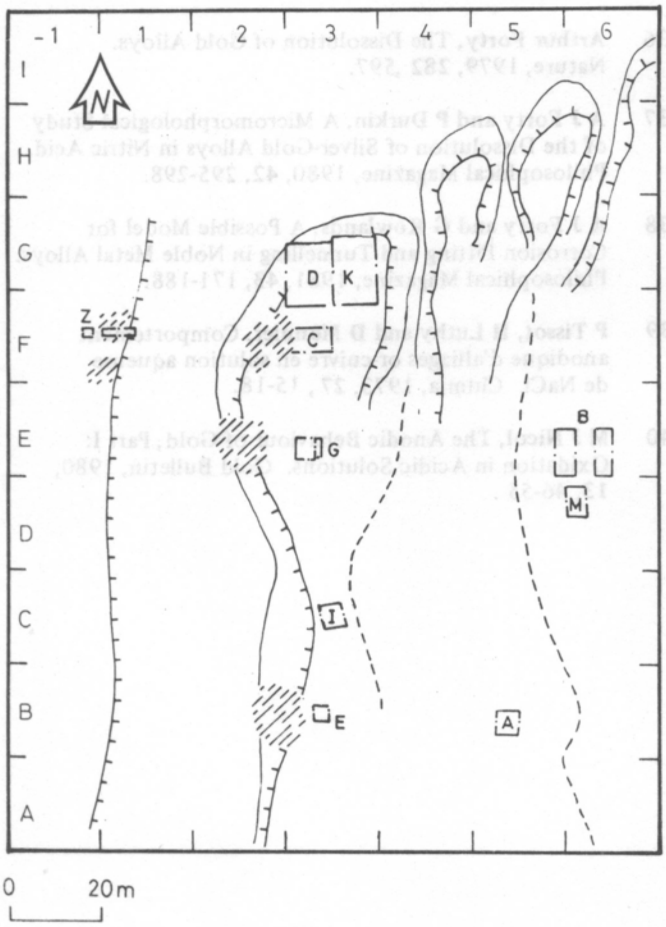

Fig 1 Plan of Site 2

Excavating Square Z/b, a unique copper smelting furnace showed up (Figs 4 and 5), cut into bedrock. In fact, there were two round rock-cut pits, separated by a low ridge, which had a narrow connecting trough cut through it, seemingly part of the tapping facility. The smaller of these two pits was the actual smelting hearth, the second, larger one, was the slag pit.

The smelting hearth: The outline of the original furnace bottom was well preserved, its diameter about 40 cm. The furnace walls were lined with clay mortar, but the lower part of the lining, from the bottom up, was found mostly broken away, as was the case in all smelting furnaces found in Timna. The backwall showed heavy slagging, but also only on its upper part. Here, part of a clay tuyere, completely covered with a thick layer of slag, indicated the position of the bellows. This tuyere appeared to have been an intentionally funnel-like indentation in the furnace wall (Fig 6), tilted at an angle of 40° - 50°. Although we found the upper rim missing, the dimensions of this tuyere could be reconstructed with the help of a large rim fragment found next to the furnace. The clay tuyere must have protruded about 25 cm above the rock surface into which the furnace pit was originally cut. The clay lining of the furnace continued behind the location of the tuyere on the rockface surface, along the edge of the hearth, probably in order to give additional strength to the installation.

The left side of the furnace wall was found missing, but its right side was almost intact down to the rock bottom of the installation. It was heavily sintered, but showed very little slagging. Although the uppermost part of the hearth, above the level of the surrounding rock surface, was not preserved, the state of the existing furnace walls seemed to indicate that there was only one tuyere to this furnace. This conclusion is supported by the previous discovery at Site No 2 of only one tuyere in the backwall of Furnace II (excavated in 1964) where the walls of the furnace were found well preserved.[4]

The rock bottom of the smelting hearth was heavily burned sandstone, which kept disintegrating even by the touch of a very soft brush. The still preserved wall of the furnace, at the back of the hearth, next to the tuyere, reached a height of 50 cm but the original furnace height was probably at least 60 cm, with a line of medium-sized stones, set in mortar around the rim of the rock cut hearth, forming its uppermost edge. One of these stones was found in situ, with its clay lining, as part of the furnace wall, and was cemented together with the tuyere.

The slag pit: The slag pit had well-preserved, straightly cut, slightly inclined walls, but the bottom was found badly disintegrating. Its diameter, as found was ca 60 cm. The low rock ridge separating the hearth from the slag pit was also badly eroded, but the lower part of the tapping hole, ca 3 cm wide, was still clearly discernible. The slag pit was about 10 cm lower than the bottom of the hearth and the tapping hole about 8 - 10 cm above the bottom of the hearth, ie the tapping aperture was about 20 cm above the slag pit bottom. We did not find any traces of the core on

Fig 2 Site 2, Area Z; in background, the main smelting site

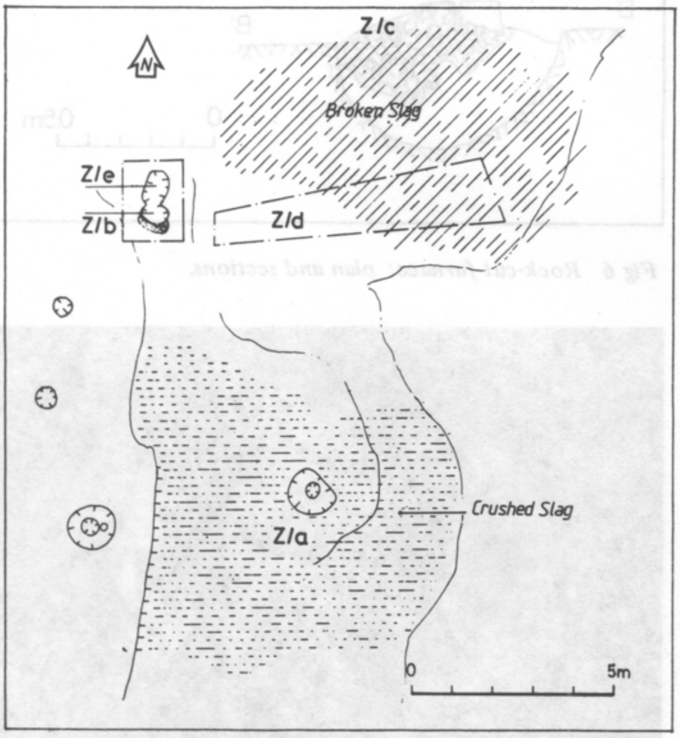

Fig 3 Plan of excavation in Area Z.

Fig 4 Rock-cut furnace at end of excavations (Scale = 1 m)

the eroded slag pit bottom[5], which must have been there to make the central hole in the circular slag cake. Such a core could well have been made of clay and was not preserved.

The slag heap: The actual slag heap started about 2 m from the smelting furnace. The ground around the smelter was kept clear of slag, but the working floor around the furnace clearly continued towards the slag heap. At the end of the smelting operation, the slag cake was lifted out of the slag pit by gripping the heavy cake at the central hole, and thrown down the slope onto the heap. Almost all of the slag circles were found broken by this action, but some could be reconstructed (Fig 7). A typical sample had a weight of 18 kg and a diameter of 43 cm. Judging by appearance, there was very little metallic copper left in the slag and there was therefore very little reason for any intentional crushing of this slag to look for entrapped metal.

The problem of the clay tuyeres: During the excavation of the rock-cut smelter and adjacent tap slag heap, we did not find any of the small clay tuyeres, typical of the smelting operations of the 19th-20th Dynasties and found in abundance at all the New Kingdom smelting sites in the Arabah and Sinai. As bellows must have been used, it now seems certain, that a tubular tuyere of a different type, built into the furnace wall, was used. Fragments of such tubular slagged tuyeres were indeed found at all sites in the Arabah, where heaps of tap slag indicated smelting installations of greater sophistication than the New Kingdom – Late Bronze Age smelters, but being similar to slagged furnace lining fragments, had not been identified as tuyere parts. We do not as yet have any indication for the type of bellows and the kind of material used for the bellows tube in the Arabah during this time.

Fig 5 Close up from above of the backwall of the furnace showing the tuyere indentation (Scale = 1 m).

The date of the rock cut smelting furnace: Area Z of Site 2 reflects in fact the stratigraphic situation of the main smelting site on the opposite side of the wadi. At the lower end of Area Z, crushed slag, small clay tuyeres, stone tools and much pottery indicated 19th-20th Dynasty New Kingdom (13th-12th cent BC) smelting activities. This layer represents the main period of Egyptian activities in the Arabah and is found at all New Kingdom sites in the Timna and Amram valleys[6]. On top of this layer and partly higher up on the slope, on previously unoccupied barren rock, obviously later smelting activities took place. There was very little pottery with the later smelting debris and this was indistinguishable from the pottery of the layer below. Considering the fact that we are dealing with an Egyptian site, or a site under Egyptian control, and the longevity of Egyptian pottery types, this should not be a surprise, but it does not help in accurately dating our rock-cut smelting furnace and the related period of copper smelting activities in the Arabah. However, we hope to get proper radiocarbon dates from the charcoal samples collected during our excavation of Area Z.

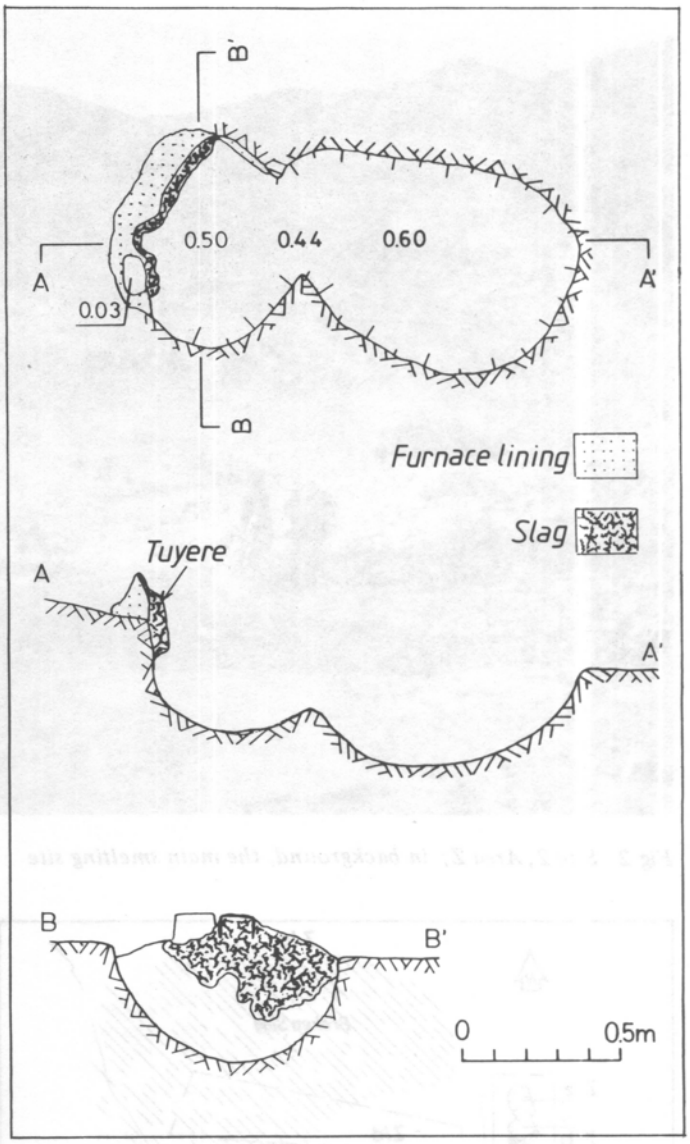

Fig 6 Rock-cut furnace; plan and sections.

Fig 7 Slag circle with cast-in hole in the centre (Scale: 20 cm sections).

Tentatively, in the frame of the Timna chronology[7], arrived at by our previous excavations and surveys, and according to the pottery found in the excavated slag heap and on the surface of Area Z, we propose to date the rock-cut furnace to the 12th 10th century BC.

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A note on some medieval pewter spoon alloys

R Brownsword and E E H Pitt

Pewter was widely used for the manufacture of domestic metalware in the medieval period, as later, but very little of this early pewterware has survived. This reflects the relative fragility of the tin-based alloys but also the well-established practice of trading-in damaged or 'bruised' pewter for re-melting. Of the tiny fraction of surviving pewter from the medieval home, the greatest number of items are spoons which, through their chance rejection with the waste-water or other fortuitous events, have been discovered in fair numbers in drains, rivers and moats. Spoons therefore offer the best opportunity for insight into the alloys used at the time and have been included, where available in museums and private collections, in an analytical survey of early pewterware being conducted at Coventry (Lanchester) Polytechnic.

Basic details only of the analytical technique are given here for reasons of limited space; 10-20 mg drilled samples taken after removal of the surface oxide were subjected to XRF spectrometric analysis using appropriate standards.

It is already clear that the composition of the pewter used for spoon manufacture was extremely variable with different tin/lead ratios, probably testimony to repeated remelting and recasting. Evidently pewter was not a binary alloy and copper was widely used at the time in small amounts (1-5%) for hardening purposes. However it is not the purpose of this note to review the subject but to report the findings on two spoons from the Herbert Museum, Coventry, which have alloy compositions of interest in relation to medieval literary sources.

The Ordinances of the Pewterers of 1348[1] laid down the nature of the pewter alloys which were to be used in making the various types of metalware. The superior grade of pewter for use in making items subject to the severest service conditions including saucers and platters was to be of *'. . . fine pewter, with the proportion of copper to the tin, as much as of its own nature, it will take.'* Various writers have speculated on the extent of the take-up of copper by the tin but there has been no recent suggestion that medieval pewter contained more than a few percent of copper[2]. However an incomplete spoon from Coventry (49/139/7), probably of the late 15th century, has been found to contain 20.8% copper along with 0.7% lead and 0.1% iron. It is possible that spoon alloys were exceptional since they were not mentioned specifically in the list of items in the Ordinance and perhaps such copper levels should not be expected otherwise; however this spoon alloy demonstrates the high levels which could be achieved.

Another incomplete spoon from Coventry (49/139/5), probably of earlier date than the above, contained 9.9% lead, 2.8% copper, 0.5% iron, 0.1% antimony and 5.8% mercury. The last ingredient has so far only been found in this spoon but there is historical reference to mercury being used to harden tin. Theophilus Presbyter's early 12th century treatise on metalworking[3] includes an account of the method for casting a pewter cruet with details of the alloy to be used. He instructs the reader: *'Immediately melt some tin in an iron pan or in a dish and when it is time for casting add a little mercury to it in such proportions that if there is a pound of tin, there should be aquarter of mercury.'* (The literal translation of the original Latin *quadrans* is used since there is some confusion over the meaning of the term.) Hatcher[4] has considered the matter and concluded that it meant a farthingweight per pound of tin (0.1% Hg) since other interpretations gave, in his view, unreasonably high levels of mercury (3.9% or 20% Hg). A quarter of a (Roman) ounce, the last word assumed, would lead to a level of about 2%. Thus the correspondence of mercury contents is not exact but the spoon represents an interesting example of an early approach to hardening tin in pewter manufacture.

The authors wish to thank Derek Janes and others of the Herbert Museum and Art Gallery for their assistance.

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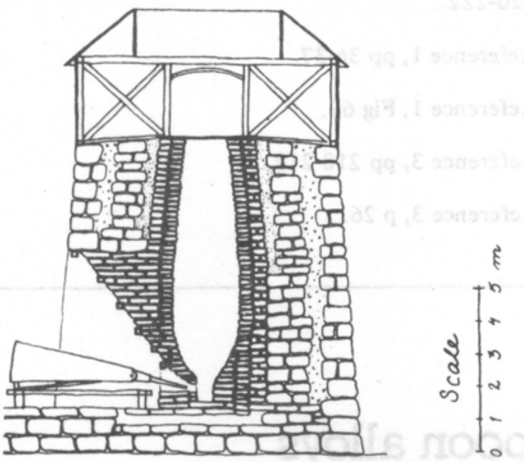
Early Blast Furnace News



1. Wheelbirks, Northumberland.

In the first issue of Early Blast Furnace News (JHMS 16/2) it was briefly reported that Dr Stafford Linsley had discovered an Elizabethan blast-furnace near Stocksfield, Northumberland. Further information now shows that this was a 're-discovery', the original sighting and excavation being credited to David Richardson in 1884 who owned the land on which it was found. Richardson published a note about his work in the Transactions of the Natural History Society of Northumberland, Durham and Newcastle, New Series I, II (1904 - 1907) pages 283-287.

In this publication, he traces the history of the site at NZ 049580 the first reference to which appears in 1566. It was known as Wheelbirks and Richardson suggested that this name arose from the water-wheel constructed to work the furnace bellows. He surmised that the furnace could not have been in operation for very long . . . perhaps a year or so . . . because only 50 to 60 cartloads of slag were spread about the surface in front of the tap-hole.

The works were then abandoned but not in haste. On the contrary everything of value was taken away, not a tool or piece of iron remained. He concluded that the enterprise, which he thought must have entailed a considerable expenditure of capital had been a failure commercially, possibly because of the insufficiency of the water supply from the Stocksfield burn.

Commenting on the Wheelbirks furnace and its connection with Richardson, Stafford Linsley[1] says:

Subsequently the site seems to have been forgotten by all but Richardson's descendants, the present owners of the land, until a brief reference to it was noticed in an unpublished local history of the Consett area. With the co-operation of the present owners, the site was re-examined and part re-excavated in April 1981.

Although Richardson almost certainly mis-interpreted some of the evidence, his note remains valuable, for much that he discovered, and laid bare, still remains. Initial confusion over the extant remains was in part clarified by Richardson's unpublished diary which referred to the fact that he had built into the collapsing furnace structure, a new supporting wall. Moreover the recent excavation revealed that he had also attempted a partial rebuilding of the furnace stack. Nevertheless, sufficient of the original structure survives to allow a partial analysis of the furnace. The present remains stand to a maximum height of 1.86m above natural level and incorporate the splayed wing walls of the tapping arch, a part-damaged crucible and fragments of the boshes. The profile is curious in that the crucible has a rectangular base about 1m long and 0.28m wide but is battered out towards the boshes. A tuyere hole, approximately 0.2m wide and 0.34m high, penetrates the longer side of the crucible, at a centre height of about 0.38m above the base of the crucible. The lower courses of the furnace pillar were extant but the blowing arch was collapsed as was the rear of the furnace, where Richardson had built the new supporting wall. No waterwheel location was determined but a possible alignment of a water race, leading about 270m back to dam foundations, was traced.

Considerable amounts of slag surround the site, some of it highly metallic with charcoal inclusions. Magnetic dating of the structure has given a provisional date for last firing 1570 ± 20 years and although there is more work to be carried out the evidence for a sixteenth century, charcoal blast furnace seems conclusive.

Reference

1 Industrial Archaeology Review, Volume VI, Number 1, 1981/2.

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2. Banwen blast furnaces, on the River Pyrddin, Neath Valley. MR SN 867105.

Two blast furnaces were erected in 1838 to exploit out-cropping iron ore along the northern edge of the coalfield. Anthracite also obtained locally, was the fuel and the furnaces were steam engine blown with hot-blast, a practice said to have been successfully used at Ynyscedwyn iron-works in 1836.

The iron produced was of high quality one sample found in 1968 assaying: carbon 2.46%, silica 3.50% manganese 0.42% with, strangely, nickel at 0.35% and copper at 0.50%.

Although capable of producing 90 tons per week, the works appeared to have been idle most of its life. One furnace was 'working' in 1849, although no production is recorded whereas 2000 tons were produced in 1853 from one furnace.

Sale of the ironworks took place in 1850. No further production is recorded after 1853, and the furnaces were 'neither standing nor working' in 1880. This information comes from the 'History of Blaencwmdulais' by Chris Evans, Cymrie Press. In fact, quite substantial remains of the stack and the engine house still exist and it is hoped that the West Glamorgan County Council will be able to restore this works, with quite a complete layout as part of a Neath Valley Industrial trail.

For this information we are indebted to Dr Martin Cahn.

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3. Springwood (Chesterton) blast furnace, Newcastle-under-Lyme, Staffs. MR SJ 821499.

This brick built stack is well known. Located rather off the beaten track it resembles Moira blast furnace in some respects. The date of the building is most likely to be 1790. Scrivenor quotes this with the owner Sir John Edensot Heathcote and the occupier Thos Kinnersley, banker and ironmonger, Mayor of Newcastle 1784. The same date is quoted in a history of iron furnaces 1795 in the B & W collection, Birmingham Reference Library. The furnace was coke fired and steam engine blown.

We are indebted to Bernard Hardman for keeping in touch with this furnace and supplying the following information.

In 1801 the furnace, then part of the Partridge Nest Ironworks was up for sale. Nothing transpired over the next decade when the works was sold up in job lots.

A note in the Heathcote papers dated to 1828 refers to the demolition of the furnace but this can only have referred to the inner firebrick lining – as this is entirely missing, at present, whereas the outer brick casing is extant.

A substantially built brick building, some 50m from the furnace appears to be the blast engine house. Excavations may produce further evidence.

The life of the furnace seems to have been short, probably due to inefficient working – another comparison with Moira?

It is with pleasure that Hardman reports that work, sponsored by Manpower Services Commission, Community Enterprise with Grants from District and County Councils is now well under way to preserve the furnace. All the ivy and tree roots in and around the furnace have been cleared and the whole brickwork exterior is now being restored, the top of the stack having been made good first.

On completion this year the restored furnace will be a focal point in the proposed Apedale Valley Country Park area.

4. Barlow blast furnace. N-W of Chesterfield, Derbyshire. MR SK 350754.

Though no longer visible, the remains were still there in the 1950s. We may have what an early cartographer thought a seventeenth century smelting house or blast furnace looked like, through the discovery by Richard Doncaster of a map dated 1630 of 'The East and West part of Barley with Dunstan and Brearley' from a book ascribed to Wm Senior.

The relevant part of this map is reproduced here and the furnace is depicted in the property shown as 'Fenderyece 3-2-0' on the Barlow brook just east of two large areas entitled 'Smithiefields'.

The Earl of Shrewsbury owned smithies at Barlow near Chesterfield in 1588 and in 1605 caused a blast furnace to be erected there. Work commenced on 19th August 1605 and the 'first sow of iron that was drawn there was of Thursday at morning about spring of the day being 27th March 1606 . . . I gave the workmen a groat and three pots of ale at Richard Greaves of the smithies'. (VCH Derbyshire 1907, 359).

Access was initially by a lane called Smelting House Lane but later another lane shown by a dotted line was driven direct to the furnace site. It is known as 'Furnace Lane'. The word 'Fender' still appears on the 6" map. It means 'to strive for a living' or 'to fund, to shift for'.

The furnace was still operating in 1693 when a lease was granted to John Jennens of Erdington Hall near Birmingham for 11 years (Hist Brit Iron & Steel Ind H R Schubert, 367). But by 1740 it had probably been closed down.

Dr R A Mott (TNS Vol 27, 235) saw the remains in the 1950s but there had been other industrial developments on

or near the site by then. A colliery shaft had been sunk and two banks of beehive coke ovens erected. All this was still visible up to 6 years ago – then a land improvement scheme was initiated around the saw mill at present active on the site. Masonry, brickwork and the excellent beehive ovens are gone. Doncaster believes that the distinctive clump of trees could possibly be a clue to the location of the 1605 stack.

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5 . Dolgun blast furnace near Dolgelly Merioneth. MR SH 752187

While attending the Annual Conference at Aberystwyth in 1977 a visit was made to a large caravan park just east of Dolgelly. Near the entrance was a heap of masonry unrecognisable as such but actually the remains of this furnace.

Douglas B Hague of the Royal Commission of Ancient Monuments in Wales and Monmouthshire, Aberystwyth had already given details to H R Schubert and a historical note appeared in JISI, February 1961.

During 1982 Peter Carew of the Snowdonian National Park Study Centre has excavated the stack and has persuaded the National Park to spend some money on conserving the fairly substantial remains which he says are comparable to Allensford blast furnace at NGR NZ 077504.

Publication of the full report on these excavations is expected in 1983.

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6. Moira blast furnace, Leicestershire. Scheduled Ancient Monument. NGR SK 314153

Dates of operation c 1804 – c 1840.

The history of this furnace was written up by Marilyn and David Palmer in Industrial Arch Review 1976, **1**, (1), 63-69.

Its curious brick structure has been and still is much a part of the scenery in this coal mining area, where the discovery of blackband ironstone in the coal measures about 1798 probably initiated the conception of iron smelting by Lord Moira.

The furnace appeared to be in operation in 1804 but it did not have a happy career. There were problems with unskilled management, faults in the furnace structure, the competition between coal for sale and coal for 'coking' for the furnace – and probably the basic problem of attempting to smelt the low grade ironstone with coal – or only partially carbonised coal – before the benefits of hot blast.

Uniquely with this furnace, the brick structure bridging from the stack to the canalside comprised cottages under the charging floor level. These were occupied along with the separate engine house, after operations ceased and up to about 12 years ago, so ensuring that the stack itself was not destroyed or vandalised. The furnace was blown out around about 1840. The hearth and bosh area were protected by bricking up as coal cellars and after occupation had ceased, the owners, the National Coal Board, then bricked up all apertures to prevent vandalism.

The North-West Leicestershire district Council purchased the furnace in 1982 with the intention of restoring it by a team sponsored by the Manpower Services Commission.

In July the team had entered the stack and commenced digging out the burden. This presented the unique opportunity to be present and record, stratigraphically, the fill down the bosh into the hearth and crucible and the well-preserved open forepart. Samples and measurements were taken, Two tuyeres were located still in situ.

The boshes were flat, approx 45° to the vertical and, at the rear of the furnace, opposite the taphole, had been severely eroded.

Permission is being sought from the DoE for further excavation after which a full paper will be prepared.

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7. Stepaside blast furnaces near Kilgetty, S Pembrokeshire, Dyfed. MR SN 142073

The local Museum authorities are requesting technical assistance in interpreting this site – said to contain a whole range of buildings covered in natural growth, on which operations commenced in 1849 and ceased in 1877, with a view to restoration and preservation.

GENERAL COMMENT

It is most encouraging to report continuing interest in early blast furnaces, new additions to the list, excavations, documentary research but, most of all, the developing interest of local authorities with access to labour and financial resources in preservation for historical and country trails.

The continued support of the DoE and interested trusts remain, of course, very much appreciated.

C R Blick

Book reviews

R W Clarke and S M Blackshaw (Eds), the Conservation of Iron, *National Maritime Museum, Greenwich. Monograph and Reports No 53, 1982. A4 format. £4.15 from the National Maritime Museum, Greenwich, London SE10 9NF. 74 pages.*

This publication contains the proceedings of a symposium held at the National Maritime Museum, Greenwich, in July 1980. It was jointly organised by the Museum and the British Museum to discuss the problems of the conservation of archaeological ironwork.

It starts with a paper by Dr Turgoose on the principles of the corrosion of iron as we now understand them, and the properties of corroded early iron in particular. Having opened with the physical properties of the corrosion film it goes on to discuss the existence of the chloride ions within the layer. Clearly, we do not yet know (or agree on) the precise position these ions take in the structure.

Mike Corfield follows with an interesting discussion on the limitations of radiography on ironwork . The showing up of weld patterns and decorative non-ferrous metals are the principal advantages. Neutron radiographs should not be overlooked.

Jim Black and S M Blackshaw then discussed the choice of mechanical and conservation cleaning chemical methods and concluded that none of the usual processes was ideal and each case has to be considered separately. Chemical techniques are not well enough inhibited and mechanical techniques are full of traps for the inexperienced.

The much discussed hydrogen reduction process was next on the agenda. Many hoped that this would be the cure-all for iron corrosion. All one had to do was to pass hydrogen-nitrogen gas mixtures over the artifacts at 400-800°C and hey-presto the chlorides would volatilise and the oxides would be reduced to solid metallic iron and the object would gain its former shape.

Barker, Kendell and O'Shea outlined the work now being carried out on the limitations of the process. It will not get rid of all the chlorides at 400°C at which temperature there is no structural change in the metal itself. But 800°C is needed over 100 hrs. for maximum chloride removal and we will still get a very porous 'sinter' which will have to be filled with an epicote resin to avoid adverse reactions and subsequent corrosion.

One treatment now being considered for archaeological iron work is lithium hydroxide, and Watkinson demonstrated that the inhibitive effect of this salt was no better than sodium hydroxide and neither of these was better than repeated aqueous boiling for chloride removal. He recommends a totally new approach to stabilisation.

On the other hand, the alkaline sulphite desalination treatment got a better bill of health, according to Rinuy and Schweizer. They treated 1 kg of corroded Roman nails from the Stuttgart museum in $NaOH/Na_2SO_3$ 0.5 M at 50°C. This chemical is a wetting agent and will penetrate through the rust to the metal core where the chlorides are most concentrated. Removing the corrosion layers before treatment only helps a little. It would appear that the residual chloride is located in the metallic core of the nails but does not seem to be sufficient to reactivate corrosion as was investigated by exposing polished iron plates to chloride solutions of increasing Cl content. The iron test plates were rapidly covered with a thin layer of rust but after 4 years there appeared to be no change.

It is claimed that the high levels of Cl, O_2 and humidity were extreme, but it seems that we cannot draw comparisons between these tests and the corrodibility of residual chlorides in a deep pore or crack in a sulphite-treated specimen.

No doubt time will tell, but this treatment does appear the best at present available .

B Knight tries to answer the question of why some iron objects do break up in store without introducing 'jacking' or the Pilling-Bedworth ratio. Shrinkage (ie dehydration) seems to be the main culprit.

Finally, we come to protective organic coatings (M W Pascoe) and corrosion inhibitors (R Walker). On the first 'there is no panacea'. In the second we are given a balanced review of the methods available. We are told of 80-85% inhibition. But the author is hopeful. He believes that the 'inhibition' of the organic coatings together with dry atmospheres will increase the protection of cleaned and stabilised iron objects.

It is clear that this symposium was a valuable focus for conservators and those working towards solving their problems. This publication with its recorded word-for-word discussion pages is important for those that did not attend and is a good reminder for those that did. At £4.15 it is not expensive. I can only hope that the conservation methods proposed here actually work and that there is plenty of iron left for the archaeo-metallurgists of the future to work on.

R F Tylecote

John K Harrison, John Gjers: Ironmaster. *Ayresome Ironworks, Middlesbrough. De Archaeologische Pers, Nederland, A4, £5 - (£6.70 post free), 102pp + plates.*

To a young man entering the iron and steel industry in 1934 on an 1877 Acid Bessemer steel plant at Workington, Cumberland, the name Gjers meant soaking pits – a simple yet logical method of retaining and equalising the heat of as-cast steel ingots in preparation for rolling.

Two years later, now with an assignment in blast furnace shift management, the name Gjers reappeared. This time the manager of the Appleby blast furnace plant, Scunthorpe, Lincolnshire – T W Thurlfield – was leaving to take over the Gjers, Mills & Co blast furnaces at Ayresome Ironworks, Middlesbrough.

So the range and technical ability of this remarkable man, John Gjers, became apparent on a personal basis. The stay of John Gjers, ironmaster at Ayresome Ironworks is now told by John K Harrison in this wholly admirable book ,published by Alex de Ouden of the Archaeologische Pers.

This is an excellent publication recording Gjers' life and the contribution he made to Cleveland blast furnace practice, in the heydays of the 1860s and 1870s and in general to the iron and steel industry.

John Harrison comments sadly that the great majority of

Victorian workshops, factories, collieries and ironworks had already disappeared before 'industrial archaeology' came on the scene and was accepted as a new and proper discipline. The records and artefacts had largely disappeared, or been destroyed, and faced with the aspect of the dying, if not actually dead, Ayresome Works – a charismatic plant of solid Victorian design and engineering – he set about a retrospective rather than a rescue project. He gathered together all available records, plans and pictures, drew a number of excellent drawings himself and has produced this well set out work comprising five sections, over some 90 pages, four appendices and a number of 'xerox-reproduced' pictures.

While doing this he found his interest moved toward John Gjers the founder of the works whom he discusses as not necessarily the most important man of the time but certainly the most interesting.

The first section deals with the Cleveland ironmaking district, its development and its workers. It is unchallenged that the district was out on its own from the early 1850s to the mid 1870s when there were 25 blast furnaces, 305 puddling furnaces, mills large and small, and auxiliary plant in the ironmasters' district. Now there is grass and shrubs and no reminder of what had been.

The second section is the biography of John Gjers, from his arrival from Sweden in 1851 to his death in 1898. In his obituary he was described as a man of great enterprise and business capacity and helped materially to work out and bring up blast furnace practice to the high standard then attained and 'he had an honourable record as an engineer and his fellow iron masters have always entertained for him the highest respect'.

The third section covers the history of the Ayresome Ironworks with a unique set of 10 fine engravings from 'Engineering' and extracts from Gjers' own paper to the Iron and Steel Institute in 1871.

In the fourth section Gjers' contributions to Cleveland blast furnace practice are set out – his design for coke ovens, calcining kiln, blast furnaces at other sites, pneumatic hoists and vertical direct acting steam blowing engines. Curiously none of his designs were taken up by other Cleveland engineers. He seemed to be at odds with developments in Cleveland, yet John Gjers made his reputation as a designer of blast furnaces to which the success of the district was due up to 1874. Then came the great depression after which American practice began to effect designs. Interest in heat exchange systems took over and his final triumph came later in his life with his soaking pit invention.

The fifth section deals with the Ayresome Ironworks after its closure in 1965 . There is a complete list of the blast furnace plant, a short dramatic note on the shut down on the 30th June 1965 and details of the recording and preservation achieved.

After John Gjers' death in 1898 a private limited company was formed to run the works . But the source of the company's ironstone was worked out by 1904 and production turned to hematite and special irons.

Fortunes varied in the early part of the twentieth century. A fifth furnace was added in 1917 but the depression reduced operations to one furnace. In 1943, the end of the Gjers family association came about, with the formation of a public company. Nationalisation followed in 1951, followed by release to private ownership in 1963 as a subsidiary of the Millom Hematite Ore & Iron Co Ltd of Cumberland. Millom was a direct competitor. Ayresome was competing in a declining market with ageing blast furnaces and antiquarian auxiliary plant and the works were now clearly at risk .

I am indebted to Mr D R G Davies, Managing Director of Millom at that time for his comment – 'This was not the way Gjers Mills saw things developing and when Millom were preparing the ground for an Ayresome closure early in 1965 they found themselves interrupting new capital development in the form of a spanking new pig bed crane ready on site for erection! Nor was it to be an easy passage for Millom to acquire, as of right, the Gjers Mills market. At least one large foundry in the Midlands swore that Gjers Mills sand cast pigs would never be matched by the machine cast product about to be foisted upon them'.

However on Wednesday June 30th 1965 the end came.

'Politely defiant to the last Gjers last department to close was the canteen and I remember having a splendid lunch on site even at the work's last gasp'

John Harrison's attitude has been similarly 'defiant' with a fight against all odds to record – and preserve – all that was possible about John Gjers and the Ayresome Ironworks.

C R Blick

Fritz Kuhn: Wrought Iron. *Harrap, London, 1982, £8.95.*

This work has not been available in a British edition for a number of years, so the present re-issue is welcome indeed. When the history of 20th century ironwork comes to be written, no blacksmith will hold a more honoured place in the development of modern smithing, than Fritz Kuhn. Without such pioneers there would have been no rebirth of creative ironwork such as we see taking place in Europe and America today.

Fritz Kuhn was aware that ironwork in Germany, as in Britain, had disastrously lost its inventive vitality somewhere around the last quarter of the 19th century; he set out through uncluttered construction, and clear honest detail dictated by traditional blacksmithing techniques, to recreate a living craft, forged, not only from the intense immediate action of the fire, but also of the mind. He believed in the importance of observing and translating, rather than copying, the shapes and rhythms of nature. The photographs with which this book is illustrated show, with superb clarity, the way in which such natural forms have been opened out and created from plain iron bars. It is particularly useful that a general photograph of a piece of work is usually augmented by a close-up of the detail, making the structure and technique so much more comprehensible than is possible in an overall view alone. They illustrate too, another basic tenet of Fritz Kuhn's smithing, the need for simplification of form.

One could wish there had been more text, which is as relevant today as the day it was written. Perhaps an assessment of Fritz Kuhn's work could have been added with advantage.

The work illustrated in this book is not of a monumental nature, such as were many of Fritz Kuhn's commissions in later life – rather it is a personal sharing of intimate work; and the smith, or anyone who appreciates the craft, will find here endless instruction and revelation – the opportunity to commune with a master.

Amina Chatwin

Hans-Gert Bachmann: The Identification of Slags from Archaeological Sites. *Institute of Archaeology, London, Occasional Publication No 6, 37 pages plus 34 pages of plates, price £10 post-free.*

The title of this monograph may suggest that it is the panacea to all the slag problems encountered by the field archaeologist, but this is not so, a fact which the author makes clear from the Introduction onwards. It introduces the archaeologist to a wide variety of slags found in association with ancient metalworking activity, discusses their origins and illustrates salient features. The monograph is divided into two parts, the first is an introduction to slags and slag formation and the second is a catalogue of illustrated examples.

A general introduction which outlines the scope and limitations of the monograph, is followed by a section on the field identification of slags. This lists many of those materials besides metallurgical slags themselves that find their way into the box marked 'slag' on the excavation, such as geological material and non-metallurgical residues. The author then offers some brief, simple macro-examinations that would aid the archaeologist in solving this problem, eg by the use of streak plates (possibly the easiest and most effective technique), texture, porosity etc. Consideration is given to the amount of (smelting) slag present on the site, and the problems of sampling, in which the archaeometallurgist should play a major part.

The next section is a check list for field surveys of archaeometallurgical sites, which makes the point that slags are only one form of evidence that is found on such sites, and must be considered within the whole context of the site.

The remaining two thirds of Part 1 discusses the laboratory methods available for slag analysis and the constitution of slags. These sections should be essential reading for any archaeologist publishing reports which include discussions on the slag found on their site. Despite the apparent endless strings of chemical symbols perseverance in reading these sections will pay dividends in the future.

The laboratory identification of slags lists techniques generally used by archaeological scientists with specific applications to slags, notably to determine their chemical and mineral compositions.

The section on the formation of slags discusses the parameters, eg ores, temperature etc which effect slag composition. The author suggests wood and charcoal as the only fuels used, (besides coal in China), but it should be borne in mind that in the highland zone, peat or peat charcoal might be a suitable alternative.

The following section on the 'chemical and phase composition of slags' will possibly be the hardest one for the non-scientist to grasp in that Bachmann introduces the difficult concept of ternary phase diagrams in less than a page. Here a larger number of references than the two given (despite their value), would have been useful, though the discussion of applications of ternary diagrams in archaeometallurgy is of value. It would have perhaps been worthwhile in the discussion on crystallisation paths in ternary diagrams that it should have been emphasised that the systems under analysis are assumed to be in 'equilibrium', which is not the case for the cooling of most slags, and deviations from the minerals theoretical composition are to be expected. Again the archaeologist will need to persevere with this section, but following up the references giving applications will help. The section on slag minerals is an extensive though not yet complete list of minerals that may occur in slags, it gives their formulae, range of composition, and possible reasons for their occurrence in slags. This section may also suffer neglect by the non-scientist, but it should be used as a reference section rather than reading straight through, and is simply ordered into silicates, oxides, sulphides, antimonides and arsenides and finally metals.

There follows a brief section on secondary slag minerals which serves as a warning that though slags are, on the whole chemically stable, leaching, corrosion and weathering of certain minerals can occur thus altering the composition of the slag.

The final section in Part 1 on additional slag properties offers two indices that may be calculated from the slag composition and be of use in extrapolating backwards to determine the conditions under which the slag formed. The first is a basicity index, the ratio of alkali to acid oxides, which is an aid to the prediction of the minerals present in a slag. The second is a viscosity index, again calculated from the ratio of basic to acid oxides, which reflects the efficiency of the technology being used. The author concludes Part 1 by stressing the fact that slags have the greatest potential as technological indicators, but there is still a vast amount of work to be done.

The second part of the monograph is a catalogue, consisting of a written description and a series of photographs, of selected examples of residues ranging from the non-slags, mentioned in the first section on the field identification of slags, through partially reduced ores to an extensive range of non-ferrous and ferrous slags.

There are nine sections spanning this range of material, under each is a brief discussion of the processes involved, followed by details of the site, date etc, from which the specimen illustrated is from, with, finally a description of the phases present in each micrograph. There are chemical analyses of the specimens either in the text or in the table at the back of the monograph.

The first section gives two examples of non-metallurgical slags and the second, an example of partially reduced copper ore. The following five sections cover the non-ferrous slags, including those deriving from the smelting of copper oxide ores, sulphide ore, lead ore, tin ore and copper slags containing tin, the last two sections have no accompanying plates. The sixth section are examples of 'speiss' inclusions of compounds of metals occurring in slags. There are seventy photographs of non-ferrous slags, macro- as well as micro-graphs, of which eight are in colour and twelve are scanning electron micrographs.

The final section in Part II deals with the slags deriving from the iron smelting and smithing processes. Clearly only the briefest of descriptions can be given in the limited space available. The iron smelting residues are dealt with sufficiently, with a discussion of some of the various residues associated with the process accompanied by a useful number of references. Smithing slags are discussed only very briefly, with the warning that it can be very difficult to distinguish between the two slag types. This slight imbalance between the discussions of smelting and smithing slags is reflected in the number of plates of each type, there being approximately two to one in favour of smelting.

Overall, this is a very useful monograph, its shortcomings are inherent in the size of the publication (the majority of the sections in Part II are probably the subject of study of a number of higher degrees at any one time), but within its covers, it holds a great deal of information, from which specialist fields can be followed up. Its value lies in helping to lift the veil that hides the work of archaeometallurgist from the field archaeologist, with the hope that slag reports may be included to play a greater role in discussion of the economy, location etc of an archaeological site. Perhaps its greatest contribution can be realised by scanning the bibliography, one notes that despite a few notable exceptions (eg the work of R F Tylecote), the advances in archaeo-metallurgical studies of ancient slags have been made abroad, this monograph is a start in redressing this balance.

J G McDonnell
The University of Aston in Birmingham
Department of Metallurgy & Materials Engineering

Steel Town – Dronfield and Wilson Cammell, 1873-1883
by John Austin and Malcolm Ford, published by Scarsdale Publications, £2.00.

This is a timely and most useful record of a unique occurrence in the development of the British iron and steel industry in the hard commercial world of late Victorian industry.

It is timely because it is the centenary of the closing of the works and its removal in entirety to the west coast of Cumberland after ten years' operations.

It is most useful because it sets straight the record on how the original company was set up, with insights on boardroom decisions, how it worked and how, in the end, the works was packed up and put on special trains – that is, the plant, not so the employees who were left to their own devices to follow at their own cost, by ordinary trains, if they wished to keep their jobs.

The authors, John Austin and Malcolm Ford, are both of Dronfield and have done a prodigious amount of research into this 'happening' – as it might be termed in today's parlance.

The proving of Henry Bessemer's method of bulk steel production meant the solution of the insatiable demand for rails by the rapidly expanding world-wide communications industry. Sheffield already had four out of the twelve existing rail mills in 1871 and three more, including Dronfield, were built by 1873.

Sheffield was not an appropriate centre for steel rail production but the steel making expertise was there. Sheffield was too far from the right sources of iron ore for the acid steel making process, and transport of steel rails by rail – to ports for the booming export requirements was costly – too costly as it proved in the end.

So while Dronfield was a suitable greenfield site in 1872 near to the heart of the country's rail system, it was not so ten years later and the bold decision was taken to move production – lock stock and barrel – to the coast where suitable iron ore, coal and port accessibility existed. This was to Cumberland's gain – and two acid Bessemer steel plants, two contiguous separate companies, produced rails for the next thirty years, when the newcomer was absorbed by the local company and closed down – but that is another story.

The transport industry which then depended on rails was the arbiter of where the producing works were sited. It remains so today with the movement, to coast-wise locations, of the most modern iron producing – and thus steel producing – plants.

The unique factor in 1883 was that a complete acid Bessemer steel making and rail rolling plant was dismantled, transported by rail and erected on another site.

There was no detritus, of a ferrous nature, left on the former site, only the remains of brickwork structures and the odd chimney. Not so these days when, for years, rusting remains of furnaces and buildings often remain to assault the eyes.

There are errors in the description of the technical process of the steel making, but the strength of this whole record is the detail of the traumatic impact on the community and social life of this small rural town dragged precipitously into a prosperous industrial scene for a few hectic years, then, more so, the tragically traumatic effect of the withdrawal of this new source of wealth, the abandonment of the community which was left to fend for itself – not to prove possible in view of dubious commercial decisions.

The steelworkers, and their families, were left with the disposal of their homes if they wished to continue working – in Cumberland – and the value of those properties plummetted. Moreover, all had to make their own, unassisted way to Cumberland to set up a new life in the small community of Moss Bay, Workington where they were soon christened the 'Dronnies'.

All this social history is recorded in detail and the whole book is recommended for the story of the meteoric rise and fall of the Dronfield Steelworks – and Dronfield industrially.

C R Blick

The Diary of George Mushet 1805 – 1813, *Edited by R M Healey, Derbyshire Archaeological Society, 1982.*

This is an enjoyable vignette on life in the iron industry when it was still virtually a cottage industry.

David Mushet is well known for his original contributions to iron manufacture and his classic papers on iron and steel. Fifty years later, the name of his younger son, Robert Forester Mushet, was to be linked with that of Henry Bessemer, in his most important contribution to the solution of the problems in the first bulk steelmaking process.

Little is known of David Mushet's younger brother, George, who travelled with him and his wife and family from Scotland in 1805 to take over the Riddings – Alfreton – Ironworks, Derbyshire. George acted as David's assistant and deputy and, while living with his brother's family, kept this short but remarkable diary over the six months he was there. He records succinctly the work he did, and cogent facts of the operation of the ironworks which produced 'fine No 1 iron' from local iron ore and coal resources.

He also observed on life in this rural community, its manners and customers and, as a strong Scots churchman, was not impressed by the discipline in the English church.

He was recalled to Scotland after six months to help his elder brother, William, manage the Dalkeith Ironworks and he records his journey back after seeing the sights of London for sixteen days.

The remainder of the diary is a commonplace book of letters and memoranda between 1806 and 1813.

This is a gentle and enjoyable record, with another sight of the remarkable Mushet family and well worth reading.

C R Blick

A blast-furnace picture on glass

Some years ago a private collector of glass bought a goblet with a very fine picture engraved right round the circumference of the bowl. Nothing was known of the history of the goblet, nor at that time, did anybody even know what the picture represented. The collector bought it simply as a splendid example of the art of the glass engraver.

More recently the Borough of Dudley opened a glass museum in the Stourbridge area, which has long been famous for its cut and engraved glass. There the owner of the goblet took it, to see if the museum people could tell him anything about it. They identified it as a 'furnace' and brought it to me for further comment.

It was easy to say what the picture represented. It shows a typical four furnace blast furnace plant of the period c1820-1840 and it is, in fact, the best picture of such a plant that I have ever seen. The detail is so good that it is obvious that the engraver worked from a contemporary drawing or painting and it is this fine detail which makes the picture so easy to identify.

The furnaces (in two pairs) are cold blast, open topped incline charged, steam blown, with haystack boilers and a blast regulator – all exactly as they ought to be for the period. The slag heap is right, too. Slag at that time was tapped into saucer-shaped depressions in the pig bed and the resulting 'cakes' of slag, when solidified, were lifted to a horse-drawn tramway wagon for dumping. There is a tripod on the pig bed which could be used for lifting the slag and there, on the right hand side of the picture, is a heap of slag 'cakes'.

The blast regulator is also right for the time. In the early years of the 19th century it was considered (wrongly!) that a steady blast was essential and regulators of various kinds were built into the blast system. This was a 'dry' regulator; simply a large receiver or vessel in which the pulses of air from the reciprocating blower evened themselves out before entering the blast main.

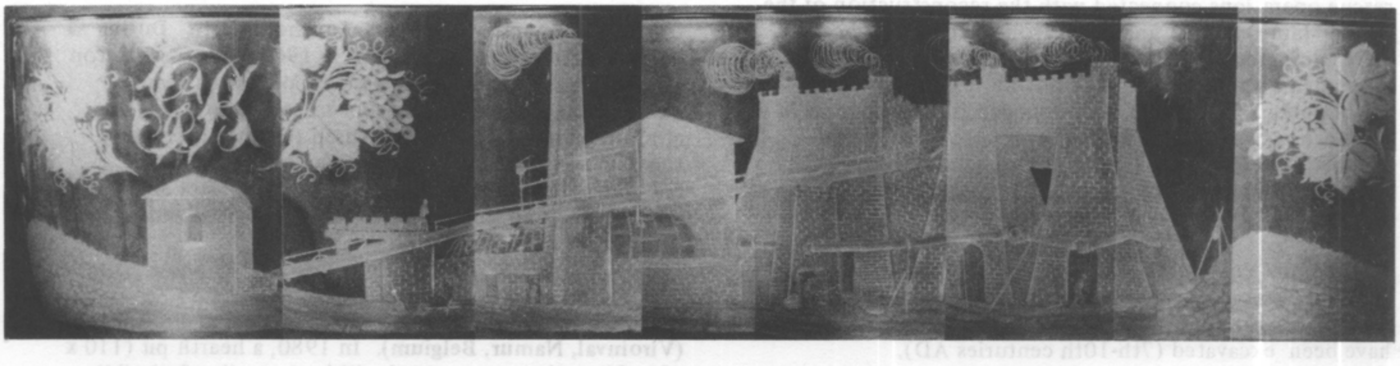
The accompanying outline sketch and notes identify the principal parts of the plant and should be generally self-explanatory. I should add that item 14 (the 'hovel') was also a common feature for the period. It served as a shelter/mess room for the men, or sometimes as a small maintenance workshop (eg a smithy). When a masonry support was being put up to carry the incline, it was easy to build a suitable recess into it.

Tunnel heads, item 17, were also a regular – and necessary – feature on open-topped furnaces. They were short brick extensions of the throat lining, and they carried the flames and smoke clear of the charging bridge and the men working on it.

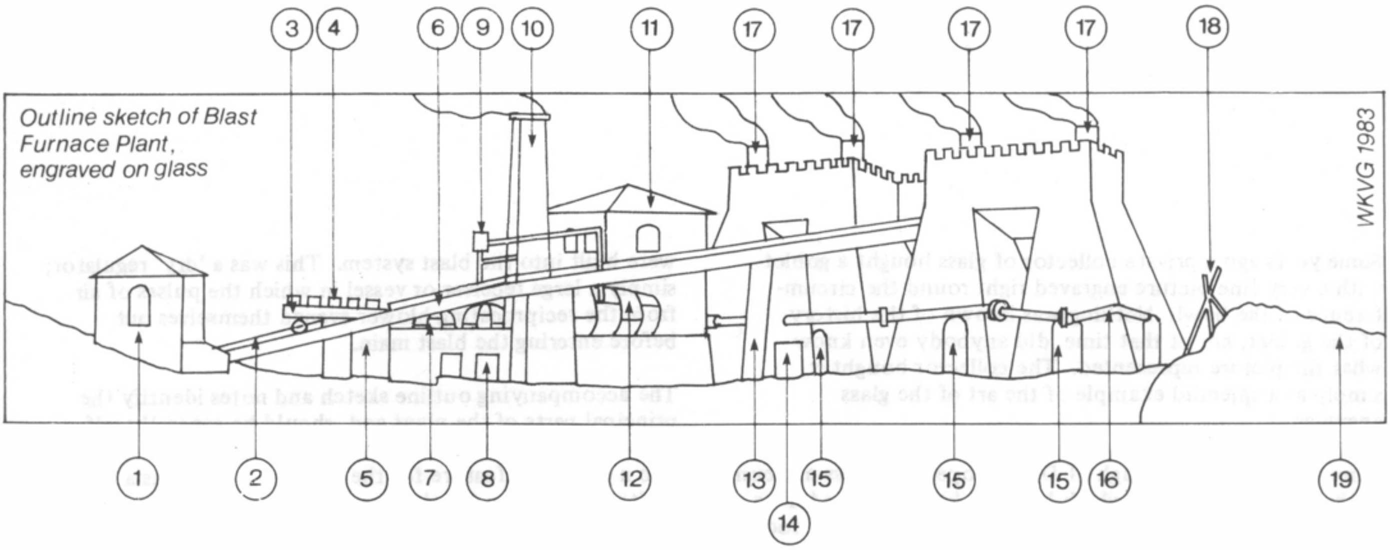
To sum up, the picture is an excellent representation of a four furnace plant of the period c1820-1840. It is almost certainly of a Black Country plant and is quite possibly of Shut End Furnaces, Kingswinford. Proof of this location is at present lacking but I am working on it.

All this information (and a lot more) was passed to the owner of the goblet who decided to present it to the glass museum, where it is now on show. It can be seen at Broadfield House Glass Museum, Barnett Lane, Kingswinford, Dudley. The museum is near to Kingswinford Cross (NG 887 888). There are direction signs at the Cross.

W K V Gale



Editor's note. *As can be imagined, photographing the engraving round the circumference of a tulip shaped goblet posed considerable technical difficulties. In the event, the people concerned, Photo-montage of Sedgley, West Midlands, took six photographs and joined them together.*



Legend for Outline Sketch

1	Incline winding engine house.
2	Winding rope or chain.
3	Incline wagon.
4	Barrows of raw materials.
5	Masonry support for incline.
6	Charging incline
7	Haystack boilers.
8	Boiler firing holes.
9	Boiler safety valve and feed pipe.
10	Boiler chimney stack.
11	Blowing engine house.
12	Blast regulator.
13	Masonry support for incline.
14	'Hovel' built in incline support.
15	Tuyere arches.
16	Blast main.
17	Tunnel heads.
18	Tripod on pig bed.
19	Slag heap.

Notes and News

EXCAVATIONS

La Tène Period Bloomery Furnaces at Essing, Kelheim District, Bavaria. In the course of major archaeological rescue operations connected with the reconstruction of the Rhine-Main-Danube-Canal, four iron-smelting furnaces were excavated on the ramparts of the Kelheim-Alkimoenis oppidum, near the northern slope of the Michelsberg. These large, dome-shaped furnaces, ovoid in plan, are very similar to that excavated by H Behaghel (**Germania**, 1940, **24**, 111-118). Three units were relatively well-preserved, up to the level of the base of the furnace.

At the same time numerous traces of both smelting and smithing were discovered in the urban area of Kelheim, where substantial portions of an early medieval settlement have been excavated (7th-10th centuries AD).

Examination of the La Tène and medieval slags was carried out by F Frohlich, of the Staatlicher Forschungsinstitut fur angewandte Mineralogie at Regensburg. Raw material resources were available on the upper plateau of the Michelsberg. Mining pits are known and have been published (see K Schwarz et al, Arch Rozled, 1969, **21**, 556).

The excavations are in the charge of the Bayerisches Landesamt fur Denkmalpflege (Abensberg Branch).

H Geisler, Munchen

Iron 'Bars' Found at Kommos, Southern Crete. During Canadian American excavations in 1981 there were 6 iron blocks (bars?) discovered in association with a temple dating from the late 9th century to ca 625 BC, near an altar. Squarish pieces of iron fused together by rust, together weighing about 15 kg, may have been in a container (basket?), now lost. Although excact analogies are lacking, it appears to be a votive deposit of semi-forged bars or billets.

After *J W Shaw,* Toronto

A Hearth within the Area of a Roman Villa at Treignes (Viroinval, Namur, Belgium). In 1980, a hearth pit (110 x 60 x 21 cms) was excavated within the walls of a building complex from the 2nd century AD. Although the hearth walls showed only slight traces of heat and nothing significant was found in the filling, a deposit of slag in front of the feature (described as A) raises the possibility of this being an iron-ore roasting hearth (limonite, oligiste).

After *J-M Doyen,* Braine-l'Alleud

Bloomery Complex of 13th Century AD at Chynice near Prague. Rescue activities by the District Museum at Beroun led to the discovery of 2 bloomery furnaces 2.4 m apart, which formed part of a complex of medieval features. The preserved hearths of both furnaces, heavily burnt and with refractory linings, were 38 and 37 cms in diameter respectively. In front of them compacted slag layers indicated tapping operations. Samples of slags and charcoal are to be analysed. The site is situated in the SW environs of Prague which is known for its iron ore deposits. After the discovery of numerous Romano-Barbarian furnaces in the region, the finding of a medieval bloomery is very important.

After *V Matousek,* Beroun

Romano-Barbarian Iron Smelting in the Neighbourhood of Hagenow, German Democratic Republic. The area south of Schwerin in the basin of the small river Sude was densely settled during the late Romano-Barbarian and Migration periods. There are also many traces of contemporary iron smelting. In many places the remains of smelting furnaces were recorded in the form of slag-pit hearths, dug into the sandy subsoil and not lined with clay. They were filled either with complex heavy slag blocks or fragments of such blocks, with charcoal, and with fragments of shaft superstructures. Charred logs of oak and beech were observed. The furnace hearths were 30-35 cms in diameter and up to 50 cms in depth.

Field survey and rescue digs organized by the Gesellschaft f Heimatgeschichte im Kulturbund der DDR, Kreis Hagenow, revealed 8 furnaces in a group, with burnt subsoil and shaft fragments at Grammitz (1972) and 7 furnaces with slag blocks on the Warrenberg near Hagenow (1969/72); at the latter site brick-shaped tuyeres were found (8 x 6 x 5 cms, with holes 1.5 cms in diameter). At Schniggenkamp-Toddiner Flur traces of a settlement and slags came to light (1972), but no furnace up to the present. At Karkwiese near Hagenow both sunken settlements and bloomeries were found; the interpretation of a large dome-shaped clay oven remains uncertain. A contemporary Urnfield cemetery is situated nearby to the east. A large bloomery site (2 ha) was discovered at Steegen (1977/82). Five furnace hearths with degraded slag blocks were investigated. Some slags were analysed: but the high silica contents and low FeO indicate slagged furnace linings. The iron making industry of the region was apparently based on exploiting bog iron ores, which are still abundant in the fields. Later, these ores were also used for building houses, churches, and city fortifications (Ludwigslust).

After *S Spantig,* Hagenow

New Romano-Barbarian Bloomery Furnaces at Prague-Dubec. Following the sunken-floored bloomery with 7 furnaces discovered in 1968 and published in AR, 1976, 28, 247-278, further workshops of a similar type came to light during rescue excavations in 1981 and 1982, occasioned by a waterpipe-line construction on the left bank of the Ricansky brook near Dubec, now within the city administration of Prague. The 1981 sunken-floored bloomery contained 2 (possibly 3) slag-pit furnaces up against the workshop wall; No 1 was very well preserved, retaining its red-burnt clay front with a manipulation aperture removing the bloom: height 63 cm, depth of the slag-pit below the hut floor 27 cm, inner diameter 31 cm; front wall 4 cm thick. A similar feature with two furnace units was excavated in 1982. The total height of the better preserved of the two furnaces was 82 cm in depth, 55 cm being the depth of the slag-pit below the workshop floor: internal furnace diameter 33 cm, front wall thickness 8 cm. The 1982 bloomery is about 300 m to the north-east of the 1981 site, the 1968 workshop being situated 500-800 m to the north. All these iron-smelting workshops belonged to a chain of Early Roman period settlement sites, bordering the Ricansky brook.

N Venclova, Prague

Tuyeres from the Phoenician Site at Toscanos, Malaga Province, Spain. This site, a Phoenician trading post of the 8th and 7th centuries BC, yielded several small clay tuyeres (blocks of 60 x 40 and undetermined length) with two parallel channels (inner diameter of about 12 mm), and various pieces of slag. According to I Keesmann (Mainz), who carried out a mineralogical investigation of the slag, it may be the result of an iron-working process. Comparable tuyeres are known from Huelva province (Rio Tinto area), from the island of Ischia (8th-6th centuries BC), and from Carthage. The double tuyeres from Carthage area, according to S Lancel, definitely connected with iron working. Some form of 'Catalan' smelting hearth, equipped with tuyeres of this type, may be postulated. The remarks of Philo of Byblos (Jacoby 790 F 2.11) on Phoenician inventions relating to the technology of iron should be considered in this context.

H G Niemeyer, Hamburg

Tintern Abbey, Gwent

The excavation and interpretation of a 17th century iron-works in the Wye Valley has earned Gwent County Council a Prince of Wales award.

The excavations were organised by Gwent County Council and carried out from 1979 until 1981. The Manpower Services Commission funded excavation work through a temporary employment programme and grants of about £7,000 towards the cost of materials came from the Welsh Development Agency. The excavations were directed by John Pickin and his reports were published in the JHMS, 1982, Vol 16, No 1 and in 1983, Vol 17, No 1.

The site is not open to the general public. Educational parties and special interest groups can visit the remains of the works – mostly the exposed remains of buildings, ponds and water courses and the remnants of the furnace – but only by appointment. Teaching packs are being prepared by the County Planning Department and Gwent College of Higher Education as educational aids.

G Prior, Chief Executive Officer's Department, County Hall, Cwmbran, Gwent. NP44 2XH. Tel: Cwmbran 67711.

EXPERIMENTAL WORK

Experimental Iron Smelting in France. In 1980 Mr Ph Andrieux, Departmental Archaeologist of the Val-de-Marne, France, organized an initial series of experimental smelts in six low shaft furnaces of the so-called Bohemian type (height 120-140 cm, inner shaft diameter 15 cm, slag-pit diameter 20-22 cm). Two systems of forced draught were used; one through a single tuyere from bellows positioned at an angle of 90° to the shaft, and the other with two bellows discharging into a single tuyere. Limonite ore was smelted either with or without $CaCO_3$ flux; the use of a flux produced more slag but the yield remained approximately the same – fibres of metallic iron scattered throughout slaggy mass.

The trials continued during 1981 at the Archeodrome (Open Air Museum and Experimental Centre) at Braune, Cote d'Or. Induced draught furnaces were tested. These did not operate well until their shaft height reached about 250 cm. Coarse charcoal fractions were preferable. The yield was virtually the same, if not slightly less, than that obtained using forced draught. The project will be continued.

After *P Andrieux*, Creteil

Experimental Bloomery Smelts at Blansko, Czechoslovakia, in 1982. Further experimental smelts were carried out in June 1982 at Blansko, in Moravia. The experimental group (K Stransky, V Souchopova, J Peiger, R Pleiner) were the guests of the Blansko Foundry Plant, whose specialists (headed by the factory director) were greatly interested and personally involved in all the operations. As models the group chose 8th century AD furnaces from Olomucany, ie the type with flat hearth and thin front wall. Since the object of the trials concerned the smelting process and not the furnace structures, the inner spaces were formed in sand moulds with steel shells. Two smelts were carried out.

Smelt BS 1: 16 kg of good Indian hematite ore (66% Fe_2O_3) were reduced using forced draught, in the unroasted state, over 3 hours, at temperatures reaching 1100°C. Result: few metallic grains and fibres in the slag. Smelt BS 2: 14 kg of the same ore, roasted and crushed to pea size, were smelted at 1200-1300°C in 2 hours. Excellent iron sponge was produced in the slag, mainly as areas of ferrite. Commercial beech charcoal was used. Detailed analyses are in progress.

At the end a lecture was given to the young students in the factory.

R Pleiner, Prague

In Britain, Roger Adams has continued his experiments on a shaft furnace in Ashdown Forest. The results are reported from time to time in the Bulletin of the Wealden Iron Research Group.

METALLOGRAPHY

Investigations of La Tène Iron from Central Germany. In connection with field excavations of the Celtic settlement at Juchsen, German Democratic Republic, a set of 10 iron implements was examined metallographically at the Museum fur Uründ Frühgeschichte, Weimar. Two of them from the early phase of the La Tene period. All the specimens exhibit piled structures with heterogeneous carbon contents (from pure ferrite up to ca 0.8% C). Only in four tools (axe, hammers, chisel) were hardenable steels with over 0.3%C identified, but traces of quench hardening occur in 7 cases with very low carbon content. Indications of tempering were also observed. A publication with full results and detailed documentation is to be expected.

H Hennig, Weimar

CONFERENCES

Spring Seminar on Economic Aspects of the History of Metallurgy of Iron was organized by the Metallurgical Section of the National Technical Museum at Prague, on the 25th May, 1982. For the ancient and early periods there were papers by R Pleiner (Comments on iron prices from the 2nd millennium BC to the 9th century AD) and by E Maur (Economic aspects of iron technology during the period of developed feudalism up to the 15th century AD).

Notes and News from Washington DC

Visitors to Japan have brought back news of a 1700-year-old sword recently excavated there. Flakes detached from this sword are being studied by the metallurgists at Nippon Steel. Studies so far tend to indicate direct influence of the Chinese on Japanese iron technology rather than an indirect route through Korea as has been thought. Miss Rajpitak Warangkhana of the conservation laboratory of the National Museum in Thailand (Narpratard Road, Bangkok 2) has completed her studies with Dr Nigel Seeley at the Institute of Archaeology, London, and is returning to Thailand. Her special interest is in high-tin bronzes. Interest in damascus steel continues. Wallace M Yater has published the first in a series of three articles on this subject in the Spring 1982 issue of the Anvil's Ring. He wishes to correspond with others interested in damascus steel and the production of wootz. His address is Route 3 Mousetown Road, P O Box 51, Boonsboro Maryland 21713. Pamela S Zener, in a special report on Archaeological Chemistry in the February 21st issue of Chemical and Engineering News, pp 26-44, included several pages on metals and metallurgy. A S Bisht, the Head of the Conservation Laboratory of the National Museum in Delhi, was on an exchange visit to the United States this spring. The technical studies section of his laboratory is specializing at present in the study of stone and metal artifacts. Bisht has the position long held by O P Agrawal, who is now in Lucknow. The TV-magazine show *'Discover'* presented an exercise in fakery and detection:; a bronze in the style of 3000-3500 BC invested at the Fogg in Cambridge, cast in Providence RI, patinated in Chicago and sent to the Freer in Washington DC for 'authentication'. Result? Stay tuned.

There have been several interesting publications in archaeometallurgy recently. MASCA(The University Museum, University of Pennsylvania, Philadelphia PA 19104) published an *Archaeometallurgy Supplement, Volume 2, Number 2 of the MASCA Journal,* which contains nine papers; and *Expedition,* the quarterly of The University Museum, devoted an issue (*volume 25, number 1, Fall 1982*) to a further six. The exhibition catalogue *'Discovery of a Lost Bronze Age: Ban Chiang'*, edited by Joyce C White (1982, University of Pennsylvania Press, 3933 Walnut St, Philadelphia PA 19104) is well illustrated and includes a sandstone axe mould from Non Nok Tha, several micrographs, and three crucibles which are shown in colour. The Council for British Archaeology (112 Kennington Road, London SE11 6RE) has published *CBA Research Report 40, 'Medieval Industry'*, edited by D W Crossley (1981, £16.00 plus 90 p overseas postage) which contain a dozen papers on medieval industries in Britain, half of them on metallurgy and mining. The Institute of Archaeo-Metallurgical Studies (The Institute of Archaeology, University of London, 31-34 Gordon Square, London WC1H 0PY) in 1981 published the first volume in its projected series on Metal in History. It is *'Studies in Ancient Mining and Metallurgy in South-West Spain, Explorations and Excavations in the Province of Huelva'* by Beno Rothenberg and Antonio Blanco-Freijeiro.

The book surveys mining and smelting sites from prehistoric to Roman times, including the great industrial complex at Rio Tinto. Nicole Echard has edited a volume of seventeen papers, all but one in French, on the traditional iron and copper metallurgy of Africa, which is to be published at the end of June. *'Metallurgies Africaines, Nouvelles contributions'* will be a *'Memoire of the Societe des Africanistes.* The pre-publication price is 145 francs (about $ 20) with 8 francs (about $ 1.10) postage, to the Societe des Africanistes, Musee d l'Homme, Place du Trocadero, 75116 Paris.

The Seminar on Chinese Archaeometallurgy held by MASCA at The University Museum on February 26th featured those four old China hands, Vincent Pigott (MASCA), W Thomas Chase (Freer, Washington DC), William Rostoker (University of Illinois, Chicago) and Ursula Franklin (University of Toronto), who gave a neatly dove-tailed presentation. Vince Pigott reported on mining and smelting, especially at the great copper mine of Tonglushan. There are very good illustrations of this site and objects from it in the pamphlet *'Tonglushan – A Pearl Among Ancient Mines'* edited by Huangshi Museum, Hubei; the Publication Committee of the Chinese Society of Metals, and the Archaeometallurgy Group of the Beijing University of Iron and Steel Technology, published in both English and Chinese, in 1980, by the Cultural Relics Publishing House, Beijing. At Tonglushan the mine sets were heavily timbered because of the friable ore. By the Warring States period a system of dropping box-like reinforcements down the adits was adopted. Stone hammers similar to those at Timna and Rio Tinto have been recovered from old open pits. Parts of smelting stacks 1½ meters high have been found. Bill Rostoker pointed out that since the Chinese furnace was never taller than 6 feet they could make use of coal; tars do not condense in short furnaces. Rostoker discussed the iron metallurgy and the Chinese development of the mass production of iron objects using such means as stack moulds, described recently in the Scientific American (January 1983). Tom Chase focussed on details of Chinese bronze casting such as their fettling and finishing practices and demonstrated how Chinese designs evolved with their technology. According to Ursula Franklin, these objects represent 'frozen choices', a particularly curious one being the fact that for 5000 years the Chinese did not choose to use metal for personal ornament.

More recent meetings included the 1983 Symposium on Archaeometry in Naples April 18-22, and the Second International Symposium on the History of Precious Metal Technology, April 25-29 at Schloss Meersburg on Lake Constance, organized by the Institut fur Museumskunde and several other German organizations and the Society of Jewellery Historians, London.

If you know of meetings being planned, or have other news to contribute, please call me at 202-357-2444 or write me at the Smithsonian Institution, Washington DC 20560.

Martha Goodway

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The international prefix for telephone numbers dialled direct is 010. This should be followed by another 1 (the USA country code) making Martha Goodway's number (from the UK) 010-1-202-357-2444.

Readers might like to know that copies of the special Archaeometallurgy Supplement to the MASCA Journal, Volume 2, No 2, 1982, can be obtained from Helen Schenck of the University Museum, University of Pennsylvania, 33rd and Spruce Streets, Philadelphia, Pa 19104, USA for 6.00 US dollars. Most of the contents of this issue are noted in the Abstracts.

Abstracts

GENERAL

J A Charles: The Metallurgical Contribution to Science-Based Archaeology. *Metallurgist and Materials Technologist, August 1982,* **14** *(8), 335-339.*

Metallurgy can not only contribute to, but could possibly derive benefit from, science-based archaeology. Investigations into the rivets of a bronze Minoan dagger, a 2300 year old silver scent bottle, and the effects of lead content in the fluidity of 5% tin bronze, are described as examples of the contributions to archaeology, while the knowledge of the technique used to form the head in a 17th century brass pin might be of value today. Problems in the use of chemical analysis as a basis for grouping artefacts in relation to one another and to an ore source are outlined. APG

Ian D MacLeod and Neil A North: Conservation of a Composite Cannon from the Batavia (1629). *The International Journal of Nautical Archaeology and Underwater Exploration 1982,* **11** *(3), 213-219.*

Discusses the structure and problems of conservation of a gun built-up from:

1. Wrought iron rings;
2. Wrought copper sheeting;
3. Lead-tin filler;
4. Yellow brass brazing;
5. Leaded bronze cascable.

Ian D McLeod: Formation of Marine Concretions on Copper and its Alloys. *The International Journal of Nautical Archaeology and Underwater Exploration, 1982,* **11** *(4), 267-275.*

Discusses the mechanism of corrosion in tropical waters and the problem of build-up of concretions on a metal that is usually reckoned as toxic to marine organisms. RFT

E G Morgan: The Ancient Craft of Casting Lead. *Foundry Trade Journal, September 9, 1982,* **153** *(3246), 401-405.*

The methods employed by early craftsmen in lead sheet and pipe-making are described and illustrated by photomicrographs of artefacts of the period.

R Pleiner: The Beginnings of Iron in Human Civilisation: *Vesmir, 1982,* **61***, 145-151. in Czech.*

The article is a popularizing summary of studies for a proposed book. It deals with problems related to possibilities of iron smelting having been discovered within the metallurgy of copper using sulphide ores, especially in south-west Asia. Chronology and the increasing frequency of iron objects and their different forms, are the criteria for the model for the spread of iron civilization in general, or more particularly, of the spread of individual stages in the making, working, and use of iron as a symbolic, and later, technical metal. The data point to the large epicentre being located in the region between Cilicia and the Armenian plateau during the full Bronze Age. Changes in the importance of iron through ages are characterized. CPSA

O Werner: Composition of Recent Reproduction Castings and Forgeries of Medieval Brasses and Bronzes. *Berliner Beitrage zur Archaeometrie, 1980,* **5**, *11-35. In German.*

This article deals with the question, to what an extent conclusions from the analysis of brass and bronzes can be drawn to the authenticity of objects from the middle ages. A large series of analysis by the author from brasses and bronzes from the middle ages and two modern founders at Berlin shows that not in every case, but sometimes, authentic object and forgeries can be distinguished. In uncertain cases other analytical techniques, like the analysis of the patina of technological examinations can be applied additionally.
Author

BRITISH ISLES

Anon: 19th Century Mechanised Moulding Involvement. *Foundry Trade Journal, August 16, 1982,* **153** *(3245), 301.*

R Jobson at Derby introduced an ingenious rollover moulding machine which could produce 1000 to 1100 railway chairs per day, compared with the normal output of a man and his boys of 300-400 per day. He also introduced a system of moulding using very accurate plaster patterns prepared from a master mould which enabled ordinary labourers to produce castings of the highest quality. In some cases, a metal pattern was permanently inset in the plasterblock to achieve a particularly good finish. APG

Peter J Brown: The Early Industrial Complex at Astley, Worcestershire. *Post-Medieval Archaeology, 1982,* **16**, *1-19.*

The mid-17th century blast furnace at Sharpley Pool is the earliest surviving example of an English furnace with a round hearth and bosh. The site had been previously excavated, and interpretation is based on the surviving excavation records and the structures themselves. Other sites within the complex include a forge/mill, packhorse bridge, and navigation works along the brook connecting the sites. The credit for their construction, as one enterprise, has long been given to the local industrial pioneer Andrew Yarranton. This traditional view is questioned by fresh research; in particular, the tinned iron buckles excavated from the forge site are shown to have no connection with Yarranton's early tin-plating experiments.

J Cherry: Post Medieval Britain in 1981. *Post-Med Arch 1982,* **16**, *226-228.*

Describes excavations carried out by P J Brown at Duddon Bridge Blast Furnace and gives plan. RFT

S S J Hughes: The Mines of Talybont. Part I. From AD70 — 1800. *Industrial Archaeology, Autumn 1981,* **16** *(3), 199-212. Illustrations pp 241, 242.*

Aerial photography has shown Roman activity in the area, and there is strong circumstantial evidence that they mined and smelted lead, silver and gold. The development of the mine from the time of the formation of the Mines Royal Society in 1568 until the end of the 18th century is outlined chiefly on a documentary basis. APG

C M McCombe: Scottish Iron Founding in the 18th and 19th Centuries. *Foundry Trade Journal, 1982,* **153** *(3251), 714-722, 735. Illustrated.*

An important factor in the development of the industry was the establishment of the large ironworks at Carron in 1760. Further impetus was provided by the opening of the Forth and Clyde Canal in 1790, and the production of cheap iron by the application of hot blast in 1829. The development of the Carron Company, the production of decorative castings, and products for railway construction are aspects especially considered.
APG

CF Tebbutt: A Middle Saxon Iron Smelting Site at Millbrook, Ashdown Forest, Sussex. *Sussex Arch Col 1982,* **120**, *19-35.*

Excavation of a 9th century AD bowl furnace, hearths and slag. Limonite and siderite ores used. The site, dated by C_{14} and Archaeomagnetism, is the first Saxon site in this area of Roman and Medieval iron smelting. PTC

P T Craddock: Report on the Metal Composition of the Ambleside Weapon in the Ambleside Hoard by S Needham. *B M Occasional Papers, 1982, No 39, pp 45-47.*

Analysis of this important hoard and comments on the casting technology. PTC

ASIA

S Cleuziou and T Berthoud: Early Tin in the Near East. *Expedition 1983,* **25** *(1), 14-19.*

Field surveys in the south west of Afghanistan has revealed ancient copper mines close to deposits of cassiterite. The problem of the origin of tin in prehistoric times in the Middle East is discussed in the light of these discoveries. PTC

P T Craddock: Corinthian Bronze: Rome's Purple Sheen Gold. *MASCA Journal 1983,* **2** *(2), 40-41.*

The discovery of a Roman bronze plaque containing small amounts of silver and gold and with a dense black surface raises speculation on the nature of semi-mythical Corinthian Bronze and connections with the Far East and Shakudo alloys.
PTC

A K Ghosh and P K Chattopadhay: An Early Steel Implement from Barudih, Bihar, India. *MASCA 1982,* **2** *(2), 63-4.*

A very early steel tool, probably for separating rice stalking, dated to 9th century BC. Metallographic studies showed a low carbon steel forged at about 900°C. PTC

L Horne: Fuel for the Metal Worker. *Expedition 1982,* **25** *(1), 6-13.*

Summarises ancient smelting technology, before concentrating on the production and use of charcoal. This survey is based in field work in Iran. PTC

T Nagaro: The History of Copper Smelting in Japan. *J Metals, June 1982,* **34** *(6), 50-53.*

The author claims there is no reliable record regarding copper production in Japan prior to the 7th century AD. Native copper was used to produce the first copper coinage in the 18th century, and a 16.2 m high Buddha statue which consumed 500 tons of copper in the mid 18th century is illustrated. In 1697 copper production was 6,000 tons, the largest in the world at the time.

The earliest extraction technique was probably the roasting of high grade ore followed by smelting in a hearth with charcoal and air blast. In the 15th or 16th century, a matte converting process was introduced. Desilverisation of molten copper by lead was introduced early in the 17th century. The first blast furnace started operation in 1876. APG

V C Pigott, P E McGovern and M R Notis: The Earliest Steel from Transjordan. *MASCA Journal 1983. 2 (2), pp 35-39.*

A number of new finds of iron dating from the 12th century BC are reported. 5 anklets and bracelets were studied metallographically. This suggested they were of steel. The absence of any carburisation evidence, and of nitrides suggests the iron may have been partially molten. PTC

V C Pigott: The Innovation of Iron. *Expedition 1983.* **25** *(1), pp 20-25.*

Reviews the origins of iron smelting technology in the Middle East. PTC

K N P Rao: Iron and Steel Technology in India in Ancient and Medieval Periods. *Metallurgist and Materials Technologist, October 1982,* **14**, *(10), 468-470.*

Written records of processes employed in the earliest days (about 1000 BC) are not available. There was probably little change before 1800 AD when Buchanan wrote a detailed description of the smelting process and the furnaces used in Southern India. Bellows were made from buffalo hide or goat skin. Crucible (Wootz) steel was made in Hyderabad State (now Andrah Pradesh), Karnataka, and Madras State (now Tamil Nadu), and the process of producing a 400 g ingot by carburizing a low carbon iron by packing with certain stems and leaves in an enclosed clay crucible is described in detail. In Madras, however, decarburisation of a high carbon iron was the technique used. Early techniques of working the steel for conversion to wire for musical instruments are described. Brief reference is made to the Delhi pillar and the iron beams in the temples of Orissa. APG

EUROPE

G E Afanas'eev and A G Nikolayenko: A Bloomery furnace of the Saltovo type. *Sovetskaya Archeologiya 1982, 2, 168-175. In Russian.*

At the site of Yutanovka in the Belgorod region an unusual below-ground bloomery furnace was excavated. Forced draught was supplied from bellows through two inclined inlet channels situated on either side of the furnace. There was an operating tunnel in the front of the loess bank into which the furnace was built. The special inner refractory lining is worth a mention. The search for analogies points to Novaya Pokrovak (similar construction, discrepancy in dating) and Volcansk (comparable dating, ie 8th - 9th centuries AD, and Saltovo cultural complex, but different original interpretation as free-standing shaft). The Moravian Zelechovice furnaces resemble the Yutanovka installation in many constructional details. CPSA

A Antejn: The Mystery of Pattern-Surface Steel. *Nauka i technika 1982, 6, 22-24. In Russian.*

The article is devoted to experiments carried out by P Anosov and N Svecov (19th century) in an attempt to imitate the genuine wootz steel which made Damascene sabres famous. It is interesting to note that new trials have recently been organized in various Russian steel plants and laboratories. For certain applications, wootz-type steels might replace expensive alloy materials. CPSA

M Biborski, P Kaczanowski, Z Kedzierski, J Stepinski: Two-Edged Swords from the Cemeteries of the Przeworsk Culture at Chmielow Piaskowy, Province of Kielce and Gac, Province of Przemysl. *Sprawozdania Archaeologiczne 1981,* **33**, *99-133. In Polish.*

The paper contains results of modern metallographical investigation of 11 iron swords of the Romano-Barbarian period B_1-C_2 from cremation graves. Four were pattern-welded with medium- or high-carbon steel edges. Morphologically, several blades are of the Roman gladius type (not all pattern-welded). The problem of imitation of pattern-welded blades outside the Roman Empire is discussed. CPSA

K Bielenin: Survey of Main Iron Smelting Areas in Poland, dating from the La Tène and Roman Periods; in Pre-Roman Iron Age in the Kattegat Region and in Poland. *Edited by I Kaelas and J Wigfors, Goteborg 1980, pp 85–106. In German.*

K Bielenin: Iron Slag as Evidence of the Relationship between Slag and Bloomery Furnace, and Vice-Versa. *Prace i Materialy Muzeum Archeologicznego i Etnograficznego w Lodzi, Ser Arch 1979,* **25**, *53-64. In Polish.* CPSA

The author stresses that the typological shapes of slag blocks, fragments etc, yield important data on furnace types (very often otherwise unknown) and dimensions. CPSA

K Bielenin: New Data Concerning the Radiocarbon Chronology of the Holy-Cross-Mountains Bloomery Sites. *Materialy Archeologiczne (Krakow), 1981,* **21**, *77-86 In Polish.*

The author adds a commentary on radiocarbon analyses carried out on fir and pine charcoal samples taken from large bloomery complexes at Lazy 6 (163 furnaces in two blocks), Nowa Slupia 11 (102 furnaces in two blocks), Grzegorzewice, and elsewhere. In spite of some surprising discrepancies in the values from individual single furnace complexes – 130 - 225 years for one bloomery (the result of 1-2 seasons) or 20-55 years for a single furnace – the author accepts the positive contribution of radiocarbon dating in solving the chronological problems of this industry. He suggests that unorganized bloomery complexes were in use between 70 BC and AD 100; fields with ordered furnace arrangements can be dated mainly to the mid 2nd century AD (archaeologically 3rd - 4th centuries). Radiocarbon dates of wood from the Rudki mine were AD 200-300. CPSA

V Dohnal: Medieval Bloomery Furnaces at Senicka in the Olomouc District, Moravia. *Prehled vyzkumu, 1981, Brno, 39-40. In Czech.*

Preliminary report on the discovery of a battery of four below-ground furnaces. The furnace profile is identical with that from Zelechovice and Olomucany, dated to about AD 800. However, the rescue excavation at Senicka yielded several 12th - 13th century sherds from the vicinity of the most westerly unit. CPSA

T Esper: Industrial Serfdom and Metallurgical Technology in 19th Century Russia. *Technology and Culture, 1982, 23 (4), 583-608.*

Based on water-power and an abundance of wood and high-grade iron ore, the iron industry of the Ural mountains was established at the beginning of the 18th century on a very large scale. Despite the remoteness of the region from centres of

large population, the industry was flourishing by the end of the 18th century, when Russia had become the world's foremost producer and exporter of iron. Russia lost its prominence in the 19th century for a variety of reasons, of which the use of serf labour was relatively insignificant. A lack of wood prevented any large scale expansion of charcoal smelting, and lack of coal until the latter half of the century prevented the introduction of cheaper, large scale, smelting by coke at a time when other countries could take full advantage of this technology. Lack of coal also prevented the large-scale utilization of steam power. Demand for iron, especially for railway construction, increased much more slowly than in the West, and the author considers that this was the major factor in delaying the introduction of the puddling process. Transportation was a problem until 1878 when the first railway in the Urals was constructed. The training of engineers left much to be desired, although new technologies were introduced as soon as they became feasible and profitable, and skilled workers were given encouragement to innovate, eg the modification of the Bessemer process and the introduction of the Rashet elliptical hearth blast furnace.
APG

John F Guilmartin, Jr: The Cannon of the Batavia and the Sacramento: Early Modern Cannon Founding Reconsidered. *The International Journal of Nautical Archaeology and Underwater Exploration, 1982,* **11** *(2), 133-144.*

Wrought iron breech loaders were the most common form from the 14th century to 16th century. Then they were replaced by cast bronze which were superior to the later cast iron cannon. But the appearance of the composite iron-bronze-soldered gun is a surprise and the author discusses the whole problem. RFT

M F Gurin: Early Iron of the Bielorussian Dniepr basin. *Minsk 1982, 125 p, 52 figs, 19 charts. In Russian.*

This is a well illustrated monograph on early iron work in the Bielorrussian area based on the metallographical investigation of numerous assemblages of artefacts; it was also intended to evaluate certain microanalytical techniques. Contents: I Investigation methods and experimental work, 11-18; II Metallurgy of iron, 19-39; III Blacksmith's work, 40-92; IV Stages in the development of iron smelting and working in the Bielorussian Dnieper area, 93-106; Conclusion, 107-109. Experimental forging of blades with sandwich construction deserve attention; they were made in order to observe carbon diffusion during welding and forging (nickel enrichment of welding seams). The list of slags and bloomery sites (4 with furnace finds) is also worthy of mention. In the author's view, poor limonites could produce yields of 12-20% iron in the bloomery process. A large number of metallographic analyses of iron artefacts dating from the 1st-11th centuries AD is presented, but unfortunately not in a very well organized manner, with the result that the relative development in the application of different techniques is not easy to follow. The explanation of various features (ageing of metal, occurrence of nitrides in ferrite grains) would also be worthy of discussion. Gurin's book represents a modern approach to the application of analytic methods to the study of archaeological iron. CPSA

E Katzer: Slav Iron Smelting at Pernitz/Muggendorft, District of Weiner Neustadt, Lower Austria. *Archaeologia Austriaca 1981,* **65***, 275-280. In German.*

A toponymic, linguistic, and historical study of a microregion on the Mira river, the results of which indicate the existence of early Slav iron mining and smelting (ie from about AD800 until the 11th century within the new German settlement). There are mining remains and reports on former slag heaps in the area.
CPSA

V D Hopak Gopak: Iron artefacts of the 8th-10th Centuries from the Monastyrok Hill-Fort, Middle Dnieper Area. *Archaeologija (Kyiv) 1982,* **39***, 100-106. In Russian.*

Seven knives, an adze, and a set of mounts and nails were examined by metallography. There were some all-steel artefacts but iron-to-steel welding and carburizing were rare.
CPSA

W A Oddy: Scientific Dating of the San Marco Horses. *MASCA, 1982,* **2** *(2). (Archaeomet. Supp), 45-47.*

Analysis of these famous statues showed them to be of almost pure copper. The horses are mercury gilded, and the metal used for the statues showed they had always been intended to be mercury gilded. Mercury gilding of statues did not start until Imperial times, thus the statues must be Roman, not Greek.
PTC

J Optalius of Trebnice: Kurtze und einfeltige Beschriebeung von denen Eisenhutten und Hammern. (A very simple and short description of an iron smelting plant). *G Hoffman ed Narodni technicke museum. Praha 1981, 151 p in Czech.*

A rediscovered treatise by Jakub Optalius of Trebnice, citizen and mayor of the city of Rokycany (SW Bohemia), written in Czech in 1647. It was previously known only in unsigned copies or in the copy by Daniel Friedrich Simalnides (1669-1670), and in later German translation (1679). It deals with the operation of an early blast furnace plant (raw materials: ores and charcoal, bellows, hearths, economy etc), and represents a rare source of information about the central European blast-furnace operations during the thirty Year's War. CPSA

A Pazdur, M F Pazdur and A Zastawny: Ancient iron production on the territories of Poland in the light of radiocarbon dates; first set of analyses. *Materialy Archaeologiczne Krakow, 1981* **21***, 87-94. In Polish.*

The C_{14} results cover all the main bloomery regions in operation during the La Tène and Romano-Barbarian periods; Holy-Cross-Mountains, Silesia (Dobrzen Maly), and Mazowsze, west of Warsaw (Biskupice, Milanowek). The authors state that the measurements demonstrate considerable deviation, being up to 10% for the Gdansk results. In addition, there are large discrepancies in the case of individual furnaces in certain furnace complexes which appear to have operated over a very limited period (Lazy; deviation of 200 years; Grzegorzewice: furnaces of one bloomery differ by more than 150 years etc). Nevertheless all the dates lay within the Late La Tène and Early Roman period; except for Milanowek, where it is pushed back to the 6th cent BC and does not accord with the archaeological information. CPSA

J Piaskowski and Z Hensel: Metallographic investigation of iron objects and slag from the early medieval cemetery at Czersk near Piaseczno. *Sprawozdania Archeologiczne 1981,* **33***, 137-148. In Polish.*

Five implements were investigated: 3 knives, a chisel, and an arrow head. The knives, the bodies of which contained high contents of phosphorus, were constructed by welding together pieces of iron and steel, the steel being in the cutting edges. Two samples of heavy bloomery slags also with high P contents (2.5 – 3.24 P_2O_5) were analysed. CPSA

G A Wagner, E Pernicka et al. The discovery of Ancient Gold Mining on Thasos, Greece. *Rev d'Archeom, 1981,* **3** *(Suppl), pp 313-320.*

Gives the analysis of grains of gold panned from streams in the area. They consist of areas of pure gold and electrum.
RFT

U Zwicker and G Constantinou et al: Investigation of Ores, Fluxes and Crucible Slag from Prehistoric Copper Smelting at Ambelikou, Cyprus. *Rev d'Archeom 1981,* **3 (Suppl)**, *pp 331-340.*

The slag was a complex silicate containing heavy metals as oxides. The minerals were reduced to give Cu with Fe, As and Pb, and silicates of Fe, Ca and Mn. RFT

Z Kedzierski and J Stepinski: Metallographic Examination of a Sword from Gostomia, Province of Radom. *Materialy Archaeologiczne (Krakow), 1981,* **21**, *65-75. In Polish.*

This is a well documented report on the metallographic investigation of a pattern-welded sword found at Gostomia (Romano-Barbarian period C_1). The central rib has two pattern-welded strips on both sides on to which very hard steel cutting edges were welded. Electron scanning microprobe revealed that the frequently observed glassy inclusions differ from bi-phase inclusions only in iron content: the lighter phases represent segregated iron oxides. In addition, some inclusions enriched in phosphorus were observed. CPSA

L S Khomutova: Blacksmithing as Evidenced from Iron Age Sites in the Smolensk Region. *Kratkyye Soobsceniya, 1982* **170**, *27-34. In Russian.*

Several scores of iron tools, mainly knives and sickles from the hill-forts at Tusemlya, Novyye Bateki, Bliznyaki, and Demidovka, belonging to various chronological phases of the Dnieper-Dvina cultures, were investigated. Their ancient owners were of Baltic origin. The object dates from three periods: 4th-2nd centuries BC, about 0, and from 5th-7th centuries AD. Frequently, pure bloomery iron and mild steel (in the author's view carburized in crucibles) were forged in the critical range below 720°C. Iron-to-steel welding and heat treatment were occasionally applied in the latest period. CPSA

M Maggetti and F Gloor: Mineralogical and Chemical Investigations on Copper Smelting Crucibles from Burgaschisee. *Bull Soc Frib Sc Nat 1978,* **67** *(2), pp 174-180. In German.*

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

V Rychner: LBA Copper and Copper Alloys in West Switzerland. *Musée Neuchatelois, 1981,* **No 3**, *pp 97-124. In French.*

A set of 84 bronze objects from a site of the urnfield period in Auvernier/Nord (Late HaB) has been submitted to a quantitative spectrographic analysis. The existence of a very homogeneous metallurgy has been proved, both in the caster's method (alloying with tin and lead) and in the basic material used. Another set of 11 objects from Neuchatel/Le Cret (early Ha B) also shows a large homogeneity. They are, however, different from those from Auvernier not only in their tin and lead alloy but also in the amount of their impurities.

J Piaskowski: On the Location of Ancient Tribe the Cotini. *Beitrage zur Ur- und Fruhgeschichte 1981,* **16**, *pp 675-686. In German.*

Classical texts on the Celtic tribe, Cotini, famous iron smelters mentioned by Tacitus are presented and discussed. Latest studies of Cuntz (1923) on 'Geography' by Ptolemaus, and earliest maps from this work published by Fischer (1932) unable to change the location of the Cotini. Several arguments showed that the Cotini smelted iron in the greatest metallurgical centre in Eastern Europe, in Gory Swietokrzyskie,-Holy Cross Mountains in Poland. Author

O P Nicholson and J G McDonnell: A study of some 18th Century Cast Iron Ammunition. *Rev d'Archeom, 1981,* **3 (Suppl)**, *203-206.*

From the Russian ship Evstaffi. The cannon ball was a grey iron with Si and P. The reinforced bar shot was also a grey iron but with low Si and P. The reinforcement was a typical wrought iron with low P. RFT

P Northover: Metallurgy in Bronze Age Archaeology. *Rev D'Archaeom, 1981,* **3 (Suppl)**, *215-240.*

S V Pankov: The development of Ferrous Metallurgy in the Ukraine from the End of the 1st Millennium BC to the 1st half of the 1st millennium AD. *Sov Ark 1982,* **4**, *pp 201-213. In Russian.*

Starts with small slag tapping bloomery furnaces. Slag-pit furnaces of the Holy Cross type were introduced at the end of the 1st mill. BC with fields of furnace bottoms in situ. This type was spatially limited and had ceased by the middle of the 1st millennium AD. RFT

J Piaskowski: The Iron Technology of the Baltic Tribes at the End of Antiquity and the Beginning of the Early Middle Ages, 1st Century BC - 8th Century AD. *Rocznik Bialostocki 1981,* **15**, *pp 11-42. In Polish; English and Russian summaries.*

Based on the examination of 70 iron implements from 19 archaeological sites and 12 samples of slag from 4 sites, the technology of the Baltic tribe, the Venedi, is described. Using high phosphorus bog ores, the Baltic metallurgists produced blooms which were locally carburized. They separated carburized parts to make cutting tools – axes, sickles – which were heat treated. No change of technology in the time from 1st century BC to 8th century AD, was observed. Author

J Piaskowski: Metallographical Investigations of Medieval Iron Implements from Krakow – Dedniki. *Sprawozdania Archeologiczne 1980,* **32**, *pp 247-270. In Polish; English summary.*

Analyses of 8 knives, 1 axe, 1 spur, 9th-12th century AD, made of bloomery iron or steel 0.06 - 0.57% P are reported. Two knives were welded and heat treated. Typical medieval Slav technology from Poland. Author

J Piaskowski: The Occurrence of Arsenic in the Ancient and Medieval Iron Implements made of Bloomery Iron. *Kwartalnik Historii Nauki i Techniki 1982, 27.2, pp 397-410. In Polish; English and Russian Summaries.*

The presence of arsenic, averaging up to 0.25% As, is reported on the iron implements from Krivina – Iatrus Bulgaria. Arsenic distribution – similarly to phosphorus – is non-uniform and promotes the formation of 'band structure', 'Zeilengefuge', 'structure en bandes'; arsenic segregation increases with increasing content. The inverse correlation between the arsenic content and the carburisation of bloomery iron is confirmed.

Arsenic increases the hardness and brittleness of iron and steel. To reveal the arsenic segregation, Oberhoffer's reagent and a microprobe analyser were used. Author

J Piaskowski: Metallographical Investigation of Early Iron Objects in the Region of Koszalin, Poland. *Slavia Antiqua 1981,* **27**, *231-252. In Polish.*

Knives, a coulter, and other artefacts from Rogowo (Early Roman period, Migration Period), Bogucin (Early Roman) and Debczyn (Late Roman period) were investigated: high phosphorus contents, wrought iron and mild steels. CPSA

R Pleiner: Investigation into the Blacksmith's Technology on Celtic Oppida. *Pamatky Archeologicke (Prague) 1982,* **73,** *86-177,*

65 iron tools from Late La Tène oppida on the territory of Czechoslovakia were submitted to standard complex metallographical examination and compared with analysed specimens from other parts of the Celtic world and beyond. Contents: Research survey; Method: Results (abridged investigation reports); Techniques (bloomery iron working 27%, medium-carbon steel working 25%, cutting edge carburizing 22%, welding together of carburized bars 22%; iron-to-steel welding in planned schemes, as the most developed technique 10%; quench hardening of hardenable steels 69%); Technological affinities; Blacksmith's failures (5%); Quality of artefacts in relation to their pointed values; Chemical anlyses. Comparitive studies showed that the craft level of the Late La Tène Celtic blacksmith was very high, resembling the technology of Antiquity or even the Middle Ages rather than that of the Northern barbarian tribes. CPSA

R Pleiner: The Technology of Manufacture of Germanic Tools and Weapons from Cremation Cemeteries in South-West Slovakia. *Slovenska Archeologia 1982,* **30,** *79-121. In German.*

28 tools (mainly knives, razors, scissors) and swords from cemeteries at Sladkovicovo, Kostolna, and Abraham were examined. Very simple techniques were applied in most of the cases: bloomery iron or medium-carbon steel were worked. Only one case showed carburization of cutting-edges and one other iron-to-steel welding. Reheated material from cremations did not permit the use of hardening techniques to be assessed. Chemically, the worked iron was very pure. Essentially, the skill and materials correspond perfectly well with those that were usual among their Northern neighbours. No technological influences seem to have come from the provincial Roman world, despite the importing of numerous goods of other kinds. CPSA

L D Pobol and M F Gurin: Iron Artefacts from the 2nd-9th Centuries AD as illustrated by Finds from the Taymanovo site, in the Mogilev Region. *Prace i Materialy Muzeum Archeologicznego i Etnograficznego w Lodzi, Ser Arch 1979,* **25,** *317-325. In Polish.*

Metallographic investigations of artefacts attributed to the Zarubincy and Bychovo cultures; piled blades and artefacts attested, no carburizing, occasionally iron-to-steel welding, 40% of objects forged from heterogeneous steel. Unfortunately, individual objects and their chronology are not specified in the text. CPSA

P Roualet, A Rapin, Ph Fluzin and L Uran: Burials at Crayon, Near Ecury-les-Repos, Marne. *Memoires de la Societe d' Agriculture, Commerce, Sciences et Arts 1982,* **97,** *25-44. In French.*

A small La Tène period inhumation cemetery included two warrior graves equipped with iron swords and a lance. These were examined by metallography. The blade from grave No 1 has been welded up from bloomery iron bars with very low pearlite; the other, from grave No 3, was heterogeneously carburized (areas up to medium-carbon steel pearlite/ferrite values). CPSA

V Souchopova: Discovery of Bloomeries dating from the 8th Century AD in the Olomucany Region Distr of Blansko, Moravia. *Sbornik Okresniho muzea v Blansku 1980,* **12,** *47-52. In Czech.*

Preliminary report on the excavation of a battery of 7 below-ground furnaces of the Zelechovice type. Another battery with 8 furnaces was situated some 200 m downstream CPSA.

M M Tolmacheva: Technology of Blacksmith's Work in Staraya Ryazan. *Soc Ark 1983 (1), 245-258.*

The author takes as her subject blacksmith's products from Staraya Ryazan, capital of the Murom-Ryazan Principality. A collection of 122 ferrous metallic objects, including 91 knives, was analysed metallographically, which permitted a conclusion about the most widespread technologies which were three-layer pile welding, face plane and scarf welding, carburizing; homogeneous-steel and iron artefacts were produced as well. Thermal treatment was applied to all objects capable of hardening. The technological level in Staraya Ryazan fully corresponded to the all-Russia level. SA

A Rupp: Metallographic Investigation of Halberds in the Historical Museum, Bern. *Jahrbuch des Bernischen Historischen Museums 1979/80,* **59-60,** *279-284. In German.*

Two of the 12 post-medieval halberds in the collection (16th-17th centuries AD) were investigated. The main type of metal was a very mild steel; in one case a more highly carburized cutting edge was observed to have been welded onto the body of the weapon. High phosphorus content. CPSA

M Sonnecken: Investigations into Early Bloomery Production in the Olpe District, Federal Germany. *Schriftenreihe des Kreises Olpe, 1982,* **6.**

Describes systematic field survey and excavation in the Olpe region, which is situated between two iron-ore areas: Sauerland and Siegerland. Of the 81 sites recorded, 7 were excavated, near Keeperkusen, Appolmicke (3), Silsmicke, Altenhof, Singeborn. Low below-ground bases with working pits in front of them were typical of the 11th-13th centuries, to which the bloomeries belong. Bellows were positioned at the sides. At Wilsmicke a complex plant was investigated; furnace, roasting plant, charcoal deposit, smithery. Analyses of bloomery slags. Metallography of an iron bar from Singeborn (welded together from 3 rods; high phosphorus and copper contents indicate Siegerland provenance). CPSA

P T Craddock: Report on the Composition of 19 Etruscan Mirrors from Danish Museums; *in Corpus Speculorum Etruscorum, Denmark 1, by H Salskor-Roberts, Odense, 1981.*

AAS Analyses of the mirrors. One was of tinned copper. PTC

J Riederer: Analyses of Statuettes from the Wurzelbauer Workshop in Nuremburg. *Berlinger Beitrage zur Arch 1980,* **5,** *pp 43-58. In German.*

At the end of the 16th century in Nuremburg, at the foundry of Benedikt Wurzelbauer (1548 to 1620) and his son Johann († 1656) cast fountains and statuettes. From one fountain and nine statuettes the alloy was analysed. It was found that they used a very homogeneous alloy, a brass rich in zinc, with a high content of lead. This alloy can be distinguished from earlier products of foundries at Nuremberg by the amount of minor and trace elements. For the foundries at Munich and Augsburg worked with bronzes at that time, products of the Wurzelbauer-foundry can be accurately determined by an analysis of the metal. Author

S Woyda: Commentary on Radiocarbon Dating of the Masovie Iron Smelting. *Materialy Archeologiczne 1981,* **21,** *95-95. In Polish.*

The iron smelting region of the Mazowsze, west of Warszawa, began in a historically brief period and from the start operated on a relatively large scale. The dating derived from surface finds and indicates the Late La Tène group up to the Romano-B Barbarian C_1 period. The bloomery site at Milanowek is among the largest. Despite the very scarce dating material, it fits in with other investigated sites in the region. However, whilst Biskupice yielded radiocarbon dates of AD 40-70, for Milanowek the dates are 490-600 BC, which does not correspond either with the general structure of the local iron production or with the beginnings of European iron smelting, in respect of the large scale of smelting activities. CPSA

J Tournaire, O Buchsenschutz, J Henderson and J Collis: Iron Age Coin Moulds from France. *Proceedings of the Prehistoric Society, 1982,* **48,** *417-435.*

Analyses of recent finds of 'coin moulds' from Levroux (Indre) and Aulnat (Puy-de-Dome), France, confirm that these objects were used for casting globules of gold and silver. Though quantitatively the majority of recorded finds come from defended oppida, more than half the sites to produce 'coin moulds' are open settlements, suggesting coin production was not centralised, at least in the second century BC. Authors

R F Tylecote (with an appendix by P T Craddock): Smelting Copper Ore from Rudna Glava, Yugoslavia. *Proceedings of the Prehistoric Society, 1982,* **48,** *pp 459-465.*

Gives the results of an experimental smelt and the partitioning of the trace elements between ore, slag and metal. Author

P G Warden, R Maddin, T Stech and J D Muhly: Copper and Iron Production at Poggio Civiale (Murlo). *Expedition 1983,* **25.1,** *pp 26-35.*

Major excavations of a 7th-6th century BC Etruscan site have produced evidence of bronze and iron working. Some of the metals from the site were examined for this article. PTC

C Lorenze and J Riederer: Analyses of Handles from Roman Jugs. *Berlinger Beitrage zur Archaeometrie, 1980,* **5,** *pp 37-42. In German.*

59 Roman handles of the 1st century AD were analyzed. It was found that different alloys were used, that is pure copper, tin bronzes with 5-10% tin on the average, lead-tin-bronzes with considerably varying amounts of lead (1-26%), pure brass with 5-25% zinc, as well as brasses with higher amounts of lead and tin. A clear dependance of the type of alloy from the technique of manufacture of these handles is obvious. Authors

E Zaitz: Preliminary Results of Excavations Concerning the Hoard of Axe-Shaped Bars found at 13 Kanonicz Street, Krakow. *Materialy Archeologiczne 1981,* **21,** *97-127. In Polish.*

This is the first systematic account of the meticulous excavation of the huge iron deposit from Krakow. Detailed documentation of the stratigraphical location of the material in a rectangular pit indicates that the date of burial must have preceded the mid-ninth century AD. The hoard consisted solely of axe-shaped bars, deposited in bundles bound together with bast ropes, to make up three main columns. The total number was 4212 pieces representing 3630 kg of iron. The principal size (80%) was 32-36 cm, the weight (65%), 0.70 - 1 kg. The shape differs slightly from that of Great Moravian examples in the shaft hole section. CPSA

AFRICA

Z A Stos-Gale and N H Gale: Sources of galena, lead and silver in predynastic Egypt. *Rev d'Archeometrie, 1981,* **3 (Suppl),** *285-295.*

Indicates that most of the sources were not Egyptian. RFT

S J Fleming and K W Nicklin: Analysis of Two Bronzes from a Nigerian Asunja Shrine. *MASCA, 1982, 2 (2), 53-57.*

Two figures dated to early 19th century shown to be of heavily leaded bronze, typical of the manillas. Lead isotope analyses also performed.

S J Fleming: Lead Isotope Analysis of Late Period Egyptian Bronzes. *MASCA 1982,* **2** *(2), 65-69.*

Group of bronzes analysed, showed similar lead isotope patterns, but these do not fit any known Egyptian sources, or the lead in ancient glass or KOHL. Suggests imports. PTC

J Riederer: Analyses of Egyptian Bronzes. *Rev d'Archaeom, 1981,* **3 (Suppl),** *239-243.*

980 leaded bronzes from German museums. Dated to 700 - 300 mostly. With summary and discussion. RFT

AMERICA

R B Gordon: The Metallurgical Museum of Yale College and 19th Century Ferrous Metallurgy in New England. *J Metals, July 1982,* **34,** *(7), 26-33.*

Much of the collection of samples of metals from the United States must have been gathered between 1857 and 1866; probably additions to the collection stopped in 1874. Samples from Connecticut have now been re-examined, and are discussed in relation to the historical background of the iron and steel industry in the area. One sample suggests that the American Silver Steel Company unsuccessfully attempted to make puddled steel in about 1865. Illustrated with photographs and micrographs. APG

H Schenck: The Iron Industry Underground. *Expedition, 1982,* **25** *(1), 36-48.*

An archaeological based survey of the development of the iron industry in the USA from its 17th century inception through the 19th century. PTC

H R Schenck: Evidence for a 19th Century Forge at Catoctin, Maryland. *MASCA Journal, 1983,* **2** *(2), 42-44.*

Rescue archaeological work uncovered the remains of sprues, risers, tools and some slag suggestive of a foundry and forge. Investigation of the slag proved inconclusive. PTC

J R White: Analyses and Evaluation of the Raw Materials Used in the Eaton (Hopewell) Furnace. *Ohio Journal of Science, 1978,* **82,** *(1), 23-27.*

Analyses of samples of the raw materials locally available for use in the Eaton (Hopewell) Furnace indicate that the iron ore and bituminous coal were of good smelting quality while the limestone (flux) was not. Because the limestone had a higher silica content and a low calcium content, it was unequal to the task of removing impurities introduced through the fuel, a combination of charcoal and raw coal, and contributed to the early demise of the furnace operation after 6 years.

J R White: Nineteenth Century Blast Furnaces of Mercer County: A Postscript. *Mercer County History, 1980,* **9,** *3-21.*

The author makes a case for the important role played by the Western Pennsylvania counties, including Mercer, in the development of the ironmaking industry. This article is in the nature of a postscript to earlier work done in Mercer County and includes a further discussion of early ironmaking, an archaeological perspective on the industry, some newly-developed techniques for evaluating the relative efficiency of the furnaces, and description of Mercer County sites. Author

E Seely: Blast Furnace Technology in the Mid-19th Century: A Case Study of the Adirondack Iron and Steel Company. *Ind Arch 1981, 7 (1), 27-54.*

The traditional image of the ante-bellum charcoal iron industry is that of a sleepy, backward sector undisturbed by the turmoil of rapid technological change. This paper establishes that the operation was representative of contemporary charcoal iron works and suggests that the industry was as aggressive in its pursuit of the latest technological advances as were the mineral fuel users who ultimately superseded it. Author

U M Franklin: Folding. A Prehistoric Way of Working Native Copper in the North American Artic. *MASCA, 1982, 2 (2), 48-52.*

Metallographic examination of small artifacts showed they had been fabricated from small nodules of native copper hammered out, annealed and folded back. The copper had been hot worked. Technique widespread over the whole Arctic region. PTC

C C Cooper, R B Gordon and H V Merrick: Archaeological Evidence of Metallurgical Innovation at the Eli Whitney Armory. *Ind Arch 1982, 8, (1), 1-12.*

Excavation of deposits of manufacturing waste at the site of Eli Whitney's armory has yielded materials that reveal new information about the metallurgical technology used at the armory in the mid-19th century. Besides evidence on the replacement of wrought iron by steel in gun barrels, the excavated materials show that, while other armsmakers adopted drop-forging for iron revolver frames, Eli Whitney, Jr, used the armory foundry to make these frames of malleable cast iron. Authors

J W Twilley and J Boyes: Composition of Columbian Tumbaga (Cu-Au-Ag Alloy) by XRF Spectroscopy. *Rev d'Archaeometrie, 1981,* **3 (Suppl)**, *303-312.* RFT

S M Epstein: The Prehistoric Copper Smelting Industry at Cerro de los Cementerios, Peru. *MASCA Journal, 1982, 2 (2), 58-62.*

24 copper smelting furnaces dated to around 1900 AD have been excavated. A rather primitive process was in use, producing prills of copper in the slag. These were melted to form ingots. These later had a high As content. PTC

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

Cover illustration

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

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

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