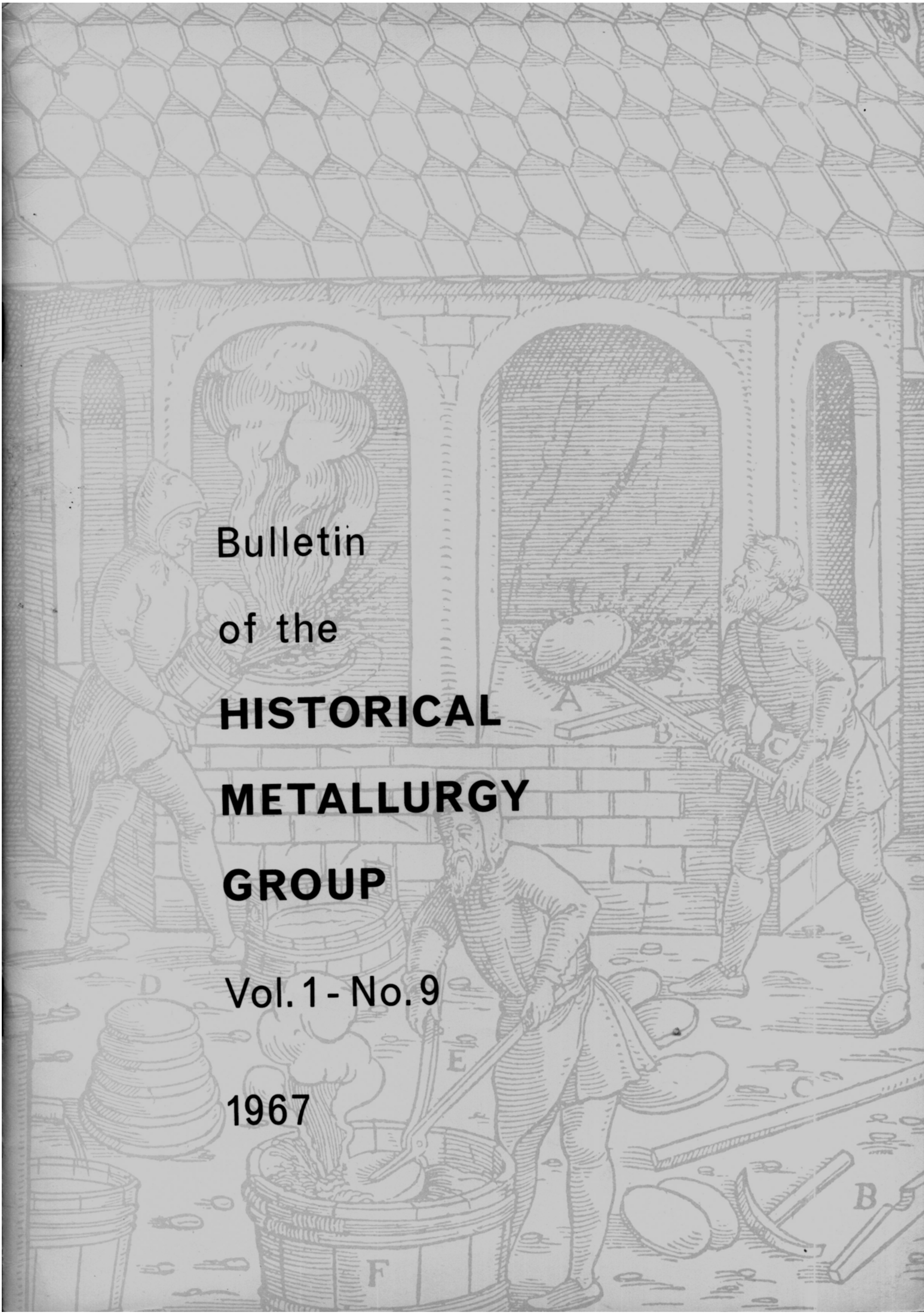

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The compositions of 35 Roman bronze coins of the period A.D. 284–363

by LAWRENCE H. COPE* and HARRY N. BILLINGHAM*

The political and economic complexities of the Roman Empire in the late 3rd and early 4th centuries A.D. are manifest in the coinage of the period, which was issued in great variety in bronze and silver-surfaced bronze (and more rarely in the precious metals), from as many as fifteen different mints spread throughout the Empire and divided between different administrations for much of the time. It is now certain that the numerous coinage adjustments and reforms, and the frequent issues of new coin types, produced metallurgical problems at the mints in rapid succession, as the moneyers—faced also with increased outputs as inflation continued almost unabated—sought to meet the demands made upon them in the most practical way, yet within the limitations of monetary policies, most probably defined in edicts which have long since disappeared.

Since the metallurgical evidence of the coinage itself can be expected to reveal something of the metallurgical practices and attainments of the time, the variations in practice between different mints, and the manner in which the moneyers executed their official instructions, it can also be expected to reveal something of the intentions of the Emperors contained in missing coinage legislation. The common bronze coinage (much of which exists to this day) provides the most valuable information with the least loss to posterity, despite the inevitable destruction of the pieces for a comprehensive metallurgical examination. So, with the generous help of a number of museum directors, curators and keepers of coins, coins representative of some of the main issues of the period (the criterion being that they were clearly identifiable though of poor museum value) have been sought and sacrificed, with impunity, for their greater worth to advances in scientific numismatics.

Metallographic studies are still in progress, but since the 35 analyses completed in less than one year by one of us (H. N. Billingham) almost equals the total number of the less completely described, and often less accurate, analytical results published for coins of the same historical span within the last century of scientific enquiry, we consider that this substantial new contribution to the existing knowledge merits early publication together with some preliminary deductions.

All the chemical analyses have been made at the Wednesbury College of Technology by the kind permission of the Principal (Mr. H. A. MacColl) and the Head of the Department of Metallurgy (Dr. G. J. T. Hume), both of whom have given the authors every encouragement and facility for furthering a project which is already beginning to provide valuable information to scholars working in the field of Roman numismatics. Since the heterogeneities of structure of ancient coins introduce complications in the preparation of representative analytical samples, we have taken half-coin (or even whole coin) samples in the case of the smaller coins, and radial segments of the larger ones, after the mechanical removal (by abrasion or filing) of the remains of corrosion products, patination, or surface silvering. For analysis, the gravimetric wet-chemical methods recommended by Caley ('Analysis of Ancient Metals', Pergamon, 1964) have been used throughout.

Fairly complete analyses have been made for all the major alloying elements and most of the more probable impurities. In every case, copper—the basic material of all the coins—has been determined (by electrodeposition) and not obtained by difference. The analysis results, mostly on duplicate samples, are given in the Table with the coinage listed in chronological order of issue, so that the trends in composition as new issues were introduced and as the coin dimensions were changed, and the consequent developments in metallurgical alloying practices, can be seen to the best advantage.

INTERPRETATION OF THE RESULTS

(1) Lead content In general it is observed that the Roman aes coinage of the early 4th century A.D. consisted almost entirely of more-or-less leaded, and argentiferous, low- to medium-tin bronzes. The lead was often added liberally, in such quantity that in the majority of cases it is clearly evident in both analysis and microstructure as the principal alloying element. There is some correlation between the lead content and the coin dimensions, the tendency being for lead content to increase as the coin sizes were diminished and, presumably, as the rate of coin production had to be increased at the mints to satisfy official inflationary measures. No doubt the moneyers were aware that by increasing the lead content they could improve the castability of the coinage bronzes and, perhaps, also reduce the overall cost of the alloys, so that smaller cast buttons for the striking of the smallest coins could be prepared both more easily and cheaply. With the coins of the highest lead contents, the effects of segregation during solidification manifest themselves visibly in the macrostructure, and make it difficult to obtain either analytical totals near to 100% or duplicate analyses which agree as closely as those of the lower-leaded alloys in which the insoluble lead phase is more uniformly dispersed.

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(2) Tin content All the coins were found to contain between 1% and 6% of tin; the contents varied considerably between the products of different mints (particularly in the earlier part of the period), but the level seems always to have been maintained within the compositional range which results in the more malleable bronze alloys desirable for coining. The few microstructures examined so far (of the large folles of A.D. 294-306) reveal that these, the largest of the 4th century coins, were hot-struck from argentiferous bronzes that had been previously heated enough to remove all traces of delta-constituent and most of the cored dendritic remnants. The heat-treatment received was probably a consequence of the surface argentifising process which was clearly used for many (if not now visible on all) of these coins. Towards the end of the period studied (c. A.D. 360), there is some evidence of a trend towards the adoption of coinage bronzes of lower tin content. This economy in tin is particularly noticeable in those coins produced by the western mints of the Empire; whether the tin content was reduced in the coinage alloys at this time for metallurgical or economic reasons (or both) it is not yet possible to judge.

(3) Silver content An outstanding feature of many of the Roman Imperial coinage bronzes of the early 4th century is that they are found to contain various small amounts of silver within the coin alloys, apart from any superficial coating. The silver contents are observed to be at levels which are too high and too consistent in particular issues for them to be interpreted as being anything other than deliberate and controlled silver additions to the bronzes, undoubtedly to produce official standard coinage alloys of specified fineness. It is of considerable numismatic interest that the analyses establish that the earliest datable folles, with the GENIO POPVLI ROMANI reverse, all contain about 3. 6% of silver in the bronze, whether they bear traces of surface silvering or not; this silver content is consistent despite considerable variations in the proportions of the lead and tin alloy components of the bronzes issued from different mints. The folles alloys appear to have been made, in the first instance, and for a longer period at the Eastern mints than in the West, to a standard of 10 scruples (20 obols) of silver per Roman pound of bronze. It is quite possible that the vexatious XXI mark, which some of the early folles of Eastern mintage bear, could refer to this silver investment, no doubt designed to engender public confidence in a token coinage which also bore some measureable and meaningful intrinsic value. The analyses of the later folles reveal a rapid series of debasements (particularly in the West), and then reductions in size and fineness which, together, effected a drastic reduction in the amount of silver invested in individual coins. This decline commenced less than a decade after the introduction of the Diocletianic follis. Later attempts at restoration need to be studies further in an attempt to establish what the changes in metallurgical practice and economic purpose really involved.

An interesting feature of a short-lived attempt at the restoration of a similar argentiferous bronze coinage (by the coinage reform of A.D. 348), is that it is now possible to discern different silver levels in coin types which have often been regarded as belonging to the same denomination. The genuine FEL TEMP REPARATIO 'Galley' coins clearly contain much more silver than another variety of the series, which is of identical size and weight (the 'Fallen Horseman' type). There is sufficient silver in the 'Galley' coin alloy, we believe, to have made its extraction a profitable pursuit to anyone with access to the pre-coined metal and a knowledge of a simple extraction process, say, by melting with lead and separating (by liquidation) the argentiferous lead for later cupellation. It is suspected, therefore, that the 'Galley' coin might be the pecunia maiorina to which an Edict of February A.D. 349 (in the Codex Theodosianus) refers, forbidding mint-workers to remove the silver from the pre-coined aes alloy, and making it a capital offence to do so.

We have also found a bronze coin which assays in the region of 1. 4% silver, and which might be the original centenionalis. One of us (L. H. Cope) bases this thesis on the supposition that the name centenionalis—meaning, literally, 'containing 100 parts'—once really indicated that the coinage alloy used contained 100 wheat-grains of silver per Roman pound of bronze. An alloy identifiable with this composition is found to have been used for an early issue (No. 25; N.M.W.1) of the 'Fallen Horseman' variety of the FEL TEMP REPARATIO series; this issue coincides with the earliest known references to centenionales in the literature. We recognise the need for more analytical results to confirm and establish some of these preliminary deductions, and it is our intention to extend this work since it is becoming abundantly clear that a detailed study of the compositions of 4th century Roman Imperial bronze coinage (and of its silver content variations in particular) will reveal further information upon which the knowledge of official coinage policies, the relationships of the numerous denominations, and the mint practices of the time may be more firmly based and the precise nature of the coinage reforms more completely understood.

(4) Impurities in the coinage alloys

We have determined four common impurities: iron, nickel, cobalt and zinc. Usually there was insufficient sample to perform separate determinations of arsenic and antimony, and so emphasis was given to the acquisition (where possible) of two separate reliable analyses for each of the eight elements listed in the Table of analyses. In no case was zinc found present in alloying amounts, as is common in much earlier Roman aes coinage alloys, nor was there any indication of its use as a deoxidiser. Iron is found to be a common and variable contaminant, but it is usually present at levels which preclude the formation of a brittle secondary phase in the microstructure; it was not harmful, therefore, to the coining properties. The nickel and cobalt levels are of particular interest for indicating the sources of the coppers used as the bases for the alloys. It is well known that the higher nickel contents can indicate copper of Middle Eastern origin, but we have no explanation to offer at present for the high cobalt levels evident in some of the coin alloys which do not contain much nickel. Ultimately, we hope that it may become possible to trace copper sources more precisely, and to reveal if coinage alloys were prepared by the mints from the nearest or local materials, or whether they were supplied to the mints (for simple re-melting) by one or more centralized metal agencies. The contemporary forgers of ancient coins, if they had no access to official materials, might be expected to have used local supplies of metal and to have compounded their own alloys as nearly as they thought necessary to simulate the metallic colour and appearance of the regular issues. There is some evidence for this in the analysis of coin No. 26 (N.M.W. 15) which is possibly a good local copy of a coin minted at the Imperial mint of Antioch, using the most readily available copper of Middle Eastern origin.

Forgeries

It is characteristic of counterfeiters that they do not waste their efforts in forging coinage of little token value nor coinage of high intrinsic worth in the same alloys as the official issues. Our evidence reveals that in the 4th century counterfeiters preferred to copy the prototypes of argentiferous bronze of some intrinsic worth (and maybe of comparatively high token value) in alloys which were usually more highly loaded, and almost void of silver (see the 'Galley' forgeries Nos. 19-21 in the Table). Thus the over-tariffed and expensive to manufacture folles were rarely copied; yet there is, to this day, an abundance of copies of the 'Galley' and 'Fallen Horseman' issues of A.D. 348 and later, which could have been more readily fabricated in leaded (but silver-free) low-tin bronzes not very different from the argentiferous alloys of the official coinage of the period. It is probable that the forgers put a quantity of lead in their bronzes for the same metallurgical and economic reasons as the officials at the mints; but, being subject to no stricter metallurgical disciplines than those necessary for the unwitting acceptance by others of their products, they tended to use more lead. For further reasons of economy they would have seen no point in adding any silver to their counterfeit coin bronzes when the small amount of silver present in the official bronze coinage alloys could not be detected visually. Both these features become evident when the analyses of the counterfeit coins are compared with the genuine prototypes in the Table.

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Analyses of Thirty-Five Roman Bronze Coins of the Early Fourth Century A.D.

No.	Code No.	Emperor	Date of issue (A.D.)	Weight (grams)	Reverse type	Mint	CHEMICAL ANALYSIS - weight per cent									Coin Reference	
							Copper	Tin	Silver	Lead	Iron	Nickel	Cobalt	Zinc	Total		
1	M. 3	Diocletian	284-294	3.07	CONCORDIA MILITVM	Antioch	92.23	3.94	1.12	0.74	0.50	0.17	0.63	0.09	99.42	1	
					(Antoninianus)		92.43	3.79	1.19	0.87	0.37	0.13	0.55	0.06	99.39	2	R.I.C.
							92.33	3.87	1.16	0.81	0.44	0.15	0.59	0.08	99.43	Av.	306
2	Br. 14	Galerius	c. 295	9.28	GENIO POP/VLI ROMANI	Siscia	90.69	3.35	3.22	2.84	0.02	0.03	0.01	0.01	100.17	1	R.I.C. VI
					(Follis)		90.32	3.36	3.03	2.75	0.03	0.02	0.01	0.02	99.54	2	
							90.51	3.36	3.13	2.80	0.03	0.03	0.01	0.02	99.89	Av.	Siscia 90 b.
3	Br. 16	Galerius	c. 300	9.07	GENIO POPV/L/I ROMANI	Alexandria	91.05	2.20	3.35	3.39	0.02	0.03	0.20	0.01	100.25	1	R.I.C. VI
					(Follis)		91.01	2.24	3.36	3.27	0.02	0.04	0.18	0.01	100.13	2	Alexandria
							91.03	2.22	3.36	3.33	0.02	0.04	0.19	0.01	100.20	Av.	31 b.
4	M. 4	Diocletian	302-303	10.98	GENIO POPV/LI ROMANI	Alexandria	90.63	2.38	3.55	3.14	0.03	0.07	0.08	0.10	99.98	1	R.I.C. VI
					(Follis)		Second Analysis sample accidentally spilled when in solution form									2	Alexandria
							90.63	2.38	3.55	3.14	0.03	0.07	0.08	0.10	99.98	Av.	34 a.
5	B. 54	Constantine I	c. 305	8.43	GENIO POP/VLI ROMANI	Lyons	87.02	4.38	1.71	6.30	0.33	0.04	0.21	0.05	100.04	1	probably
		(as Caesar)			(Follis)		87.16	4.45	1.69	6.43	0.37	0.06	0.20	0.06	100.42	2	R.I.C. VI
							87.09	4.42	1.70	6.37	0.35	0.05	0.21	0.06	100.25	Av.	Lyon 179 a.
6	B.M. 53	Maximian	307	6.43	GENI/O P ROM	London	86.07	5.56	1.85	6.44	0.01	0.02	0.01	0.01	99.97	1	R.I.C. VI
					(Reduced Follis)		85.88	5.22	1.83	6.68	0.01	0.04	0.02	0.02	99.70	2	London 90
							85.98	5.39	1.84	6.56	0.01	0.03	0.02	0.02	99.85	Av.	
7	B.M. 56	Constantine I	315-316	3.97	SOLI INVI/CTO COMITI	Rome	80.55	4.97	0.82	12.76	0.07	0.07	0.05	0.03	99.32	1	R.I.C. VII
					(Much-reduced follis)		80.05	5.12	0.83	13.34	0.10	0.09	0.04	0.01	99.58	2	Rome 40
							80.30	5.05	0.83	13.05	0.09	0.08	0.05	0.02	99.47	Av.	
8	B. 80	Constantine I	320-324	2.40	VOT. XX in wreath	Rome	88.96	4.79	1.87	4.51	0.03	0.02	0.01	0.01	100.20	1	Kent (N.C. 1957)
							88.11	4.48	1.83	4.95	0.04	0.04	0.01	0.01	99.47	2	No. 537
							88.54	4.64	1.85	4.73	0.04	0.03	0.01	0.01	99.85	Av.	
9	B.M. 59	Constantine II	322-323	3.49	BEAT TRANQLITAS	London	95.20	0.21	1.83	1.71	0.41	0.02	0.06	0.01	99.45	1	R.I.C. VII
					VOT/IS/XX		95.65	0.41	1.85	2.00	0.43	0.03	0.03	0.01	100.41	2	London 259.
							95.43	0.31	1.84	1.86	0.42	0.03	0.05	0.01	99.95	Av.	
10	Y. 2	Constantine I	324-330	2.41	PROVIDEN/TIAE AVGG	Cyzicus	89.72	4.43	1.22	4.05	0.04	0.10	0.07	0.01	99.64	1	L.R.B.C. I
							89.50	4.28	1.40	4.05	0.05	0.10	0.08	0.01	99.47	2	1188
							89.61	4.36	1.31	4.05	0.05	0.10	0.08	0.01	99.57	Av.	
11	Ch. 14	(Urbs Roma)	330-335	2.14	Wolf and twins	Trier	87.14	2.42	0.94	9.35	0.62	0.03	0.08	Nil	100.58	1	as L.R.B.C. I
							86.72	2.40	1.01	8.95	0.71	0.07	0.11	Nil	99.97	2	70
							86.93	2.41	0.96	9.15	0.64	0.05	0.10	Nil	100.24	Av.	
12	W. 5	Constans	337-341	1.59	VIRTVS AVGG NN	Trier	76.72	3.20	Nil	19.34	0.04	0.05	0.03	0.02	99.40	1	L.R.B.C. I
							75.74	3.21	Nil	19.89	0.04	0.07	0.03	0.01	98.99	2	117
							76.23	3.21	Nil	19.62	0.04	0.06	0.03	0.02	99.21	Av.	
13	B.M. 26	Constans	341-347	1.16	VICTORIAE DD AVGGQNN	Trier	77.59	6.03	Nil	16.13	0.05	trace	0.02	Nil	99.82	1	possibly
							Insufficient sample for a duplicate analysis									2	L.R.B.C. I
							77.59	6.03	Nil	16.13	0.05	trace	0.02	Nil	99.82	Av.	116
14	W. 4	Constantine I	341-347	1.63	VN MR	Alexandria	80.05	2.95	0.44	16.22	0.08	0.10	0.07	0.01	99.92	1	L.R.B.C. I
							81.83	2.78	0.35	14.83	0.02	0.12	0.06	0.01	100.00	2	1473
							80.96	2.87	0.40	15.53	0.05	0.11	0.07	0.01	100.00	Av.	
15	W. 3	Constantine I	341-347	1.74	VN MR	Alexandria	78.09	4.26	0.26	17.36	0.02	0.02	0.02	0.02	100.05	1	L.R.B.C. I
							78.09	3.47	0.54	17.74	0.01	0.04	0.04	0.02	99.95	2	1477
							78.09	3.87	0.40	17.55	0.02	0.03	0.03	0.02	100.01	Av.	

No.	Code No.	Emperor	Date of issue (A.D.)	Weight (grams)	Reverse type	Mint	CHEMICAL ANALYSIS - weight per cent: Copper	Tin	Silver	Lead	Iron	Nickel	Cobalt	Zinc	Total		Coin Reference
16	Ch. 18	Constans	348-350	4.19	FEL TEMP REPARATIO (Galley)	Alexandria	84.74	3.24	1.65	9.60	0.10	0.22	0.13	0.06	99.74	1	probably
							84.87	3.32	1.59	9.35	0.08	0.24	0.16	0.07	99.68	2	L.R.B.C. II
							84.81	3.28	1.62	9.48	0.09	0.23	0.15	0.07	99.73	Av.	2831 or 2835
17	B.M. 17	Constans	348-350	4.25	FEL TEMP/REPARATIO (Galley)	Trier	83.14	2.55	2.20	11.41	0.10	0.06	0.21	0.02	99.69	1	L.R.B.C. II
							81.60	2.61	2.14	12.96	0.10	0.05	0.17	0.03	99.66	2	43
							82.37	2.58	2.17	12.19	0.10	0.06	0.19	0.03	99.69	Av.	
18	B.M.5	Constans	348-350	4.05	FEL TEMP/REPARATIO (Galley)	Trier	78.43	2.40	2.35	16.55	0.22	0.03	0.04	0.008	100.03	1	L.R.B.C. II
							78.03	2.54	2.15	16.95	0.19	0.07	0.03	0.011	99.97	2	46
							78.23	2.47	2.25	16.75	0.21	0.05	0.04	0.010	100.01	Av.	
19	B.M. 6	Contemporary forgery Constantius II	348+	5.83	FELTEM/REPRARTIO (Galley)	copy of Trier	73.74	1.65	0.36	23.45	0.20	0.03	0.09	0.04	99.56	1	
							74.84	1.91	0.36	22.51	0.02	0.04	0.07	0.03	99.78	2	–
							74.29	1.78	0.36	22.98	0.11	0.04	0.08	0.04	99.68	Av.	
20	B.M. 7	Contemporary forgery Constantius II	348 +	3.62	/PMSTIET (Galley)	copy of Trier	85.71	2.48	0.43	10.65	0.06	0.06	0.19	0.05	99.63	1	
							85.09	2.48	0.42	11.16	0.07	0.05	0.10	0.07	99.44	2	–
							85.40	2.48	0.43	10.91	0.07	0.06	0.15	0.06	99.56	Av.	
21	W. 6	Contemporary forgery Constans	348 +	4.7	FEL TEM/PREPARATIO (Galley)	copy of Lyons	73.05	1.91	0.36	24.64	0.02	0.04	0.12	0.01	100.15	1	copy of
							74.78	2.15	0.48	22.45	0.02	0.03	0.10	0.01	100.02	2	L.R.B.C. II
							73.92	2.03	0.42	23.55	0.02	0.04	0.11	0.01	100.10	Av.	185
22	B.M. 11	Constans	348-350	5.45	(Double struck) FEL TEMP. REPARATIO (Hut)	Rome	87.68	2.32	1.10	7.89	0.12	0.08	0.14	0.04	99.37	1	as L.R.B.C. II
							87.90	2.17	1.09	8.17	0.09	0.09	0.14	0.06	99.71	2	604
							87.79	2.25	1.10	8.03	0.11	0.09	0.14	0.05	99.56	Av.	
23	B.M. 13	Constans	348-350	2.56	FEL TEMP REPA/RATIO (Hut)	Rome	89.71	2.16	1.20	6.73	0.09	0.07	0.16	0.05	100.17	1	as L.R.B.C. II
							89.90	2.24	1.01	6.57	0.07	0.05	0.14	0.03	100.01	2	604
							89.91	2.20	1.11	6.65	0.08	0.06	0.15	0.04	100.10	Av.	
24	B.M. 21	Constantius II	348-350	2.34	FEL TEMP REPARATIO (Phoenix)	Cyzicus	78.75	2.72	0.25	16.94	0.05	0.09	0.21	0.08	99.09	1	as L.R.B.C. II
							78.14	2.56	0.29	17.88	0.06	0.06	0.18	0.08	99.25	2	2483
							78.45	2.64	0.27	17.41	0.06	0.08	0.20	0.08	99.19	Av.	
25	N.M.W.1	Constantius II	348-350	4.69	FEL. TEMP RE/PARATIO (Fallen Horseman, 2)	Aquileia	90.35	3.35	1.31	4.20	0.12	0.16	0.07	0.08	99.64	1	L.R.B.C. II
							90.58	2.87	1.47	4.12	0.14	0.14	0.08	0.08	99.48	2	893
							90.47	3.11	1.39	4.16	0.13	0.15	0.08	0.08	99.57	Av.	
26	N.M.W.15	Possibly a forgery Constantius II	348-350	4.19	FEL TEMP RE/PARATIO (Falling Horseman, 4)	Antioch	88.15	2.25	Nil	7.36	0.08	0.24	0.06	0.06	98.20*	1	possibly a copy of
							88.11	2.24	Nil	7.50	0.08	0.22	0.08	0.07	98.30*	2	L.R.B.C. II 2620
							88.13	2.25	Nil	7.43	0.08	0.23	0.07	0.07	98.26*	Av.	
27	B. 85	Magnentius	351-353	6.08	SALVS DD NN AVG ET CAES (Chi-Rho monogram)	Uncertain (Gallic)	92.61	2.22	Nil	3.41	0.14	0.09	0.17	0.07	98.71*	1	L.R.B.C. II
							93.04	2.05	Nil	3.30	0.16	0.08	0.12	0.04	98.79*	2	19, 20, 22, 23
							92.83	2.14	Nil	3.36	0.15	0.09	0.15	0.06	98.78*	Av.	62, 236 or 445
28	B.M. 46	Constantius II	351-354	4.25	FEL TEMP RE/PARATIO (Falling Horseman, 3)	Heraclea Thracica	89.66	1.82	0.63	6.94	0.06	0.11	0.05	0.04	99.31	1	
							89.23	2.22	0.61	6.84	0.08	0.11	0.06	0.04	99.19	2	L.R.B.C. II
							89.45	2.02	0.62	6.89	0.07	0.11	0.06	0.04	99.26	Av.	1893
29	Y. 4	Gallus	351-354	2.15	FEL TEMP/REPARATIO (Falling Horseman, 3)	Thessalonica	83.58	1.78	Nil	12.93	0.48	0.22	0.14	0.07	99.20	1	possibly
							83.20	1.74	Nil	13.22	0.50	0.24	0.12	0.04	99.06	2	L.R.B.C. II
							83.39	1.76	Nil	13.08	0.49	0.23	0.13	0.06	99.14	Av.	1682
30	B.M. 18	Constantius II	353-354	3.78	FEL TEMP RE/PARATIO (Falling Horseman, 3)	Amiens	91.63	1.26	0.22	6.97	0.07	0.07	0.05	0.03	100.30	1	
							91.39	1.14	0.15	7.21	0.08	0.04	0.06	0.04	100.11	2	L.R.B.C. II
							91.51	1.20	0.19	7.09	0.08	0.06	0.06	0.04	100.23	Av.	25
31	B. 86	Constantius II	c. 355	1.99	FEL TEMP/REPARATIO (Falling Horseman, 3)	Uncertain (perhaps Eastern)	84.16	1.52	0.69	12.66	0.07	0.10	0.05	0.03	99.28	1	
							83.92	1.40	0.50	12.90	0.05	0.10	0.02	0.01	98.90	2	uncertain
							84.04	1.46	0.60	12.78	0.06	0.10	0.04	0.02	99.10	Av.	
32	B. 89	Julian II	355-360	1.94	SPES REI/PVBLICE	Aquileia	68.87	3.15	Nil	24.35	0.20	0.04	0.14	0.08	96.83*	1	L.R.B.C. II
							72.04	4.25	Nil	19.28	0.25	0.02	0.08	0.04	95.96*	2	952, 954 or
							70.46	3.70	Nil	21.82	0.23	0.03	0.11	0.06	96.41*	Av.	956

No.	Code No.	Emperor	Date of issue (A.D.)	Weight (grams)	Reverse type	Mint	CHEMICAL ANALYSIS - weight per cent: Copper	Tin	Silver	Lead	Iron	Nickel	Cobalt	Zinc	Total		Coin Reference
33	B. 87	Constantius II	355-361	1.39	SPES REI/PVBLICE	Cyzicus	67.92	2.41	Nil	24.20	0.04	0.10	0.08	0.01	94.76*	1	possibly
							68.82	2.39	Nil	24.87	0.02	0.14	0.05	0.03	96.32*	2	L.R.B.C. II
							68.37	2.40	Nil	24.54	0.03	0.12	0.07	0.02	95.55*	Av.	2504 or 2506
34	B.M. 42	Julian II, Caesar	358-360	1.58	SPES REI/PVBLICE	Rome	63.01	0.57	Nil	35.06	0.01	0.04	0.15	0.06	98.90	1	L.R.B.C. II
							63.51	0.67	Nil	33.66	0.01	0.04	0.18	0.08	98.15	2	692
							63.26	0.62	Nil	34.36	0.01	0.04	0.17	0.07	98.53	Av.	
35	N.M.W. 22	Julian II, Augustus	361-363	7.18	SECVRITAS REIPVB (Bull and two stars)	Nicomedia	91.63	1.18	1.31	4.86	0.03	0.08	0.03	0.03	99.15	1	L.R.B.C. II
							91.85	1.20	1.34	4.93	0.03	0.10	0.01	0.01	99.47	2	2319
							91.74	1.19	1.33	4.90	0.03	0.09	0.02	0.02	99.32	Av.	

* Heavily corroded coins; low analysis totals due to internal corrosion penetration.

A metallurgical examination of eleven palstaves

by H. H. COGHLAN*

Of the eleven palstaves examined, ten are typologically datable to the Middle Bronze Age and the eleventh (OA 325) to early in the Late Bronze Age, i.e. after 1000 B.C. in southern Britain.

This work was undertaken in order to determine the method of manufacture from the characteristics of the microstructure. The chemical analyses are given in the Table together with a summary of details of manufacture and the hardness.

(1) NEWBURY MUSEUM No. OA. 265.

Found in a pond at Bagnor, near Newbury, Berkshire

This is a large and rather rough tool; the butt of the implement has been severely hammered and the cutting-edge badly notched. The patination is of a dark chocolate colour and appears to be fairly uniform and stable. Upon visual examination, corrosion attack does not appear to be of a serious nature. The palstave has clearly been cast in a bi-valve mould; the stop-ridges and the deep and strong flanges are clearly features which have been incorporated in the casting as a whole. In places the cutting-edge remains sharp, and it was possible to obtain a fair section from the edge for metallographic examination. For the purpose of examining the metal in the body of the palstave far removed from the cutting-edge, a control section (Section B), was removed from the side of the implement just below the stop-ridge, and at a distance of 75 mm from the blade. At this position one would hardly expect to find a casting of this nature worked or intentionally heated to any extent. The total length of the palstave is 144 mm, and the width over the blade is 64 mm.

Examination—Unetched

Examination of the polished surface of the cutting-edge section showed the metal to be extremely clean and sound and without any major defects. Alpha-delta eutectoid was not observed. Throughout the whole section examined, a fine network of small spots was seen. It is difficult to say what these spots are; possibly they derive from porosity. While the edges of the specimen have suffered from corrosion, penetrative attack is very slight. The cutting-edge has suffered some damage through mechanical bending. Examination of the polished surface of the metal of the control section B showed similar characteristics to that of the cutting-edge section. Along the sides of the specimen (section B), patination is remarkably thin but penetrative corrosion attack is slight and over considerable distances it may be said that there is virtually no corrosion attack.

Examination—Etched

Using alcoholic ferric chloride, this is a difficult metal to etch and it gives the impression of being rather inert to the etching reagent. Upon etching the cutting-edge section, the structure revealed predominantly consists of residual coring but, with difficulty, upon heavy etching a background structure of very small equi-axed twinned crystals could be seen, implying that recrystallization had just occurred. Heating was at a low temperature, possibly in the region of 350-400°C. The above-mentioned crystals are so small that they can only clearly be seen at magnifications of 100 and over, and the unsatisfactory etching conditions render them unsuitable for photography. Upon etching the section with ammonia hydrogen peroxide, the strong residual coring is very clearly brought out. It also shows that the residual cores are flowed in the region of the cutting edge under the action of hammering or forging.

Hardness values taken showed that the metal had been brought up to a state of remarkable hardness, HV5 values of 239 being recorded at the cutting edge, and 161 in the body of the section remote from the cutting edge. To attain such a degree of hardness, much high-frequency hammering must have been resorted to. Examination of the control section B revealed a structure which is substantially the dendritic one of the cast metal. At one or two places upon the outside edges of the specimen, extremely small twinned crystals could just be seen, implying that, in these isolated locations, recrystallization had just commenced and that at these few points the metal had been subjected to slight local plastic deformation. However, it may be said that this part of the palstave was practically unworked, no flowing or disturbance of the cores being observed.

To sum up the evidence of this palstave, it was quite accurately cast to the finished shape in a bi-valve mould and it is highly probable that most of the metal was left substantially in the 'as cast' state, the casting being

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* Honorary Curator, Borough Museum, Newbury

cleaned up and finished cold by mechanical work, as are small bronze castings to the present day. A feature of note in the case of this palstave is the very high degree of hardness that the smith managed to impart to the cutting-edge of the blade by means of cold hammering; this hardening was surely intentional. Again, it is interesting to observe that the casting was gently heated all over, the recrystallization temperature still being attained at a distance of not less 75 mm from the end of the palstave at the cutting edge of the blade.

(2) NEWBURY MUSEUM No. OA. 324.

From Weybridge, Surrey, England

This palstave is of a bronze colour and is well patinated. Superficially it is in excellent condition and shows no external evidence of corrosion attack. The blade is widely splayed and the cutting-edge is extremely sharp and quite undamaged. The implement has obviously been cast in a bi-valve mould for on both sides the casting flashes are to be seen. The side wings are clearly cast as a whole with the rest of the implement. These wings are not very deep, standing as a maximum at about 8 mm above the median web, but they are of substantial cross-section, being about 5 mm in thickness where they merge into the median web, tapering off to about 2.5 mm at the top. The median web itself is a substantial one with a thickness of some 3 mm at the butt, tapering to a thickness of 11 mm at the stop-ridges. On one side of the palstave a marked stop-ridge has been incorporated in the casting but, on the other side, although indicated by a slight beading, a stop-ridge is almost absent. Here, the moulding for the casting was defective. In this palstave the wings are perhaps longer than is usual since they extend down the sides of the blade to within about 40 mm from the curved cutting edge of the blade. The total length of the implement is 160 mm, and the width over the splayed blade is 64 mm.

Three sections were removed for metallographic examination. One section was taken through the cutting edge. Another, section B, was taken through one of the cast wings at a distance of about 105 mm from the blade and at approximately the mid-length of the wing. Section C is from the side of the blade about 50 mm from the cutting-edge. Here, the section takes in the commencement of the long wing, and visual inspection suggests that the wing has been hammered at this point in antiquity.

Examination—Unetched

Examination of the polished surface of the cutting-edge section showed the metal to be unsound with very considerable porosity. In the region of the cutting-edge and along the sides of the specimen there is widespread intercrystalline penetration and corrosion on crystallographic planes. There are some non-metallic inclusions which are probably of slaggy origin and, throughout the whole section examined much lead was observed. Alpha-delta eutectoid was not noticed. In this section there are a number of small and scattered pools of redeposited copper. Examination of the polished surface of section B, taken through one of the wings, showed the metal apparently to be of excellent quality, clean and sound, and corrosion attack may be said to be absent. For tin, the analysis figure indicates 8.5%, but in section B a large quantity of eutectoid is observed, and therefore the actual tin content is perhaps of higher order. It is also possible that segregation of the eutectoid has occurred. Lead was not observed in this section. Section C, taken from the side of the blade about 50 mm from the cutting-edge, showed the metal to be excellent and without apparent defects. Patination is extremely thin and it may be said that corrosion attack is absent. Throughout the section a large quantity of alpha-delta eutectoid is seen. It will be noted that much lead was observed in the cutting-edge section, but this element is not recorded in the other two sections. This is unexpected but, since palstaves would appear to have been cast vertically with the cutting edge as the lowest point, gravity segregation could be severe.

Examination—Etched

The cutting edge section presented some difficulty in etching and satisfactory photography of the structure was not attained. Upon etching the specimen with alcoholic ferric chloride, it was possible to discern a general structure of very small equi-axed twinned crystals superimposed upon a dark and featureless background which is probably that of very diffused relics of the cast structure. The structure suggests that recrystallization had just occurred and that the heating was at a low temperature, probably around 350-400°C. Under relatively strong magnification it could be seen that the very small crystals were predominately slip-banded, indicating a terminal cold hammering operation probably directed towards an intentional hardening of the metal. Owing to the unsuitable nature of the metal hardness tests upon the cutting edge were not taken. In section B, taken through one of the cast flanges, upon etching the structure revealed is substantially that of the annealed casting; in view of the fact that the alpha-delta eutectoid present appears quite sharp and unrounded, it may be assumed that the anneal was a moderate one. At one localized position upon the rounded tip of the flange a region of small twinned crystals is seen, showing that, at this point, there had been plastic deformation, and that the recrystallization temperature had been reached. It is not suggested that the flange had been intentionally worked because a few accidental blows during fabrication would be quite sufficient to lead to local recrystallization of this nature. It may be said that in general the structure throughout this section is that of the original casting, unworked, and in more or less annealed condition. In the case of Section C it was found upon etching that much of the exterior surfaces had been plastically deformed, probably by cold work, and then heated to the recrystallization temperature. In general in many places along the edge of the specimen a structure of rather small twinned crystals was revealed, and slip banding was not observed in these crystals.

In the mass of the metal the twinned crystals are not seen and the structure becomes that of the partially annealed casting. The sides and edges of the specimen have been worked by hammering, but the working was of limited extent and the metal appears to have been left in annealed condition.

To sum up for this palstave, it was found that the cutting edge had been worked, heated, and finally hardened. At a distance of about 50 mm from the cutting edge the blade had been worked and heated to recrystallization temperature. The wing, or flange, examined about 105 mm from the cutting edge, was found to have been heated but not mechanically worked. Hence, the whole palstave has been subjected to a general heating, and has been mechanically worked at a distance of 50 mm above the cutting edge, and possibly even further. It is clear that heating and mechanical working were by no means confined to a restricted region at the cutting-edge.

Except at the cutting edge, the metal of this palstave is apparently of very good quality in the sections examined. In the cutting edge section, where the metal has suffered corrosion attack, a number of small pools of redeposited copper were observed. In sections B and C no occurrence of such copper could be seen.

(3) **NEWBURY MUSEUM** No. OA. 93.

From Ireland

Upon visual inspection this palstave appears to have suffered little from corrosion attack since the bronze-coloured patination is good and stable. The cutting edge remains very sharp and is practically undamaged. The stop-ridge of this palstave is a slight one, and the side wings or flanges, are unusually deep; these flanges appear clearly to be cast with the rest of the implement as a whole. In places, the flanges have been cracked, probably due to hammering with the object of closing them around a shaft; they are now slightly bent inwards and, as they stand, would not withdraw from a mould. One might perhaps think that the cavity to form such wings would be too deep to have been cut in a stone mould, but for this there are parallels in the Irish stone mould (see Coghlan and Raftery in SIBRIUM, VI, 1961, pp. 223-244). It would appear that the metal of the flanges is cold-short since fracture occurred upon but relatively slight bending. The total length of the palstave is 152 mm, and the maximum width over the blade is 56 mm.

Besides the normal section from the cutting edge, two further sections were taken out for metallographic examination as follows:

Section B This section was taken about 65 mm from the cutting edge. Here, there is a heavy mass of metal just short of the wings or flanges, and the cross-section of the palstave is approximately 30 mm wide and 16 mm thick at this point. The metallographic section taken covers the full width of the blade from one side to the other. At this position, one would not expect the casting to be forged because the metal is very far removed from the cutting edge, where working is to be expected. Section C This is a section taken through one of the flanges. As previously mentioned, the flanges or wings are very thin and deep, the depth attaining a maximum of some 14 mm, and the thickness is only 3-4 mm at the root of the flanges, reduced to 2.5-3 mm at the tip of the flange. A point of interest about these wings or flanges is that, upon the outside, the tips of the flanges have a groove along their length which recalls the grooving upon the edges of the blades of some spearheads and daggers. By visual inspection one cannot say if the grooves are a feature of the casting or may have been ground or chased in as a finishing operation upon the metal.

Examination—Unetched

Examination of the polished surface of the cutting edge section showed the metal to be very clean, sound, and without visible defects. Penetrative corrosion is extremely slight. Alpha-delta eutectoid was observed throughout the section. In Section B (approximately 65 mm from the cutting edge), there is considerable porosity in the mass of the metal, but around the exterior surfaces is a wide band of clean and sound metal, as if consolidated by forging. At one or two places there had been local corrosion attack, but in general the exterior surfaces have suffered very little from corrosion, and intercrystalline penetration was not observed. A considerable amount of alpha-delta eutectoid is seen and the eutectoid is well rounded, indicating that the metal has been considerably heated. In general, the metal appears to be remarkably free from inclusions, non-metallic or otherwise.

In Section C (taken from the flange or wing), the metal is extremely clean and sound; in fact, it may be described as excellent metal. There is very little corrosion attack upon the exterior surfaces and no intercrystalline penetrative corrosion could be seen. A certain amount of alpha-delta eutectoid is visible in the polished specimen; some of the eutectoid has been rounded and a few islands appear to have been plastically deformed and elongated or drawn-out.

The same thing may be said in the case of a number of small non-metallic inclusions, which are probably of slaggy origin. The inference is that the flange metal has, at some time in its history, been hot-worked and hammered.

Examination—Etched (Alcoholic ferric chloride)

Upon etching the cutting edge section, the structure was seen to consist of medium-size equi-axed twinned crystals, and throughout the section the crystals are slip-banded; from the cutting edge, there is an increase in crystal size as the mass of the metal is entered. Within normal etching time no relics of coring or dendritic shading are observed and it would appear that the metal approaches uniformity of composition. The metal has clearly been heated and worked; the working may have been carried out cold followed by annealing. However, at the cutting edge there is a suggestion that the extreme tip may have been hot-worked at some time, since some small inclusions, probably of slaggy origin, appear to have been plastically deformed and drawn out into fine stringers; the same thing is also observed at other positions in the section but, if there was hot working at the cutting edge, it was insufficient to cause plastic deformation of the eutectoid present. The cutting-edge of this tool has been hardened, the terminal operation being cold hammering (no doubt intentionally to harden the edge). This is confirmed by hardness determinations, 206 HV_5 being recorded at the cutting edge and 142 HV_5 in the mass of the metal remote from the edge. Hence, for a bronze, a high degree of hardness was attained.

Upon etching Section B, the structure revealed is that of a worked and fully annealed tin-bronze. Coring has been eliminated and the metal probably approaches uniform composition. Except for one small region in the mass of the metal, the whole section exhibits equi-axed twinned crystals of medium size, only a very few slip-banded crystals were observed, and the metal has been left substantially in annealed condition. Upon etching Section C the structure seen is of rather large twinned crystals throughout the whole section. Coring has been eliminated and the metal would appear to approach a uniform composition. It is clear that this flange metal has been worked and annealed, and it is very probable that during some stage in fabrication hot working has been resorted to. Although in places slip-banding of crystals was observed, in general, the metal is left substantially in annealed condition.

To sum up it was found that the cutting edge of the palstave has been thoroughly worked and annealed, and there is a suggestion that there may also have been some hot working. Hardness testing showed that the cutting edge has been work-hardened to a high degree, a figure of 206 HV_5 being here recorded. Examination of Section B also revealed a worked and fully annealed structure which has been left in substantially annealed condition. In the case of the wing, or flange, Section C, the metal has again been worked and annealed and it is very probable that during some stage in fabrication hot working has been resorted to. Again, the metal of the flange section has been left in the annealed state. The general quality of the metal in the casting, and the treatment of the cutting edge, indicate considerable skill both in the melting of the metal and working of the alloy.

In the case of this palstave it is clear that the whole implement has been strongly heated all over. It has certainly been forged or hammered where the three sections have been taken, and was quite probably so treated in other localities, if not throughout. From knowledge of the moulds that have been found for casting of palstaves, it may be assumed that the casting was produced practically to the finished dimensions and should only have required the normal cleaning up. Hence, it is not clear why the smith (or founder) resorted to so much working and heating.

(4) NEWBURY MUSEUM No. OA. 322.

From Ireland

This palstave has a widely splayed blade and is a well finished tool in undamaged condition. The patination is of dark chocolate colour and there is a certain amount of corrosion attack to be seen on the surface, but this does not seem to be active or serious. Stone and metal moulds that have been found show that the flanges of palstaves were usually cast solid with the rest of the implement in a bi-valve mould; upon visual inspection, this example has all the appearance of having been so cast. The wings or flanges appear to be slightly bent in; probably they were cast parallel to each other in the normal manner and then an attempt was made to close them by hammering. The flanges are not deep and only stand 6 mm above the median web; however, for their depth they are quite substantial being, on average, about 3.5 mm thick. The stop-ridges, while clearly marked on the casting, are merely symbolic and are of hardly any value as functional stops. Quite possibly this tool is transitional from the winged axe to the palstave. The total length is 123 mm, and the width of the splayed blade is 52.5 mm.

For metallographic examination three samples were removed. One specimen was taken through the cutting edge. Section B was taken from one of the wings or flanges, and section C is from one side of the blade about 45 mm from the cutting edge. At this point the blade is 10 mm thick, and the section covers the full thickness of the blade from one face to the other.

Examination—Unetched

In both the flange and cutting edge sections the metal appears to be good and no defects were observed. There is considerable corrosion along the sides of the specimens, but deep penetration is limited to one or two locations. In both of these sections there is a considerable quantity of alpha-delta eutectoid to be seen, which suggests that the alloy in general contains more than 5.8% of tin. In the cutting edge section some plastic deformation of the eutectoid was observed, which suggests hot working. In the flange section there is clear evidence to show that hot working had been resorted to during some stage in the history of the metal.

Here, hot working has caused plastic deformation of the eutectoid without fragmentation, and the eutectoid has been elongated and curved round to follow the contour of the flange. It is not suggested that the flanges were raised by forging, but they were clearly hot-forged in an attempt to close them in. Since the flanges are of heavy section and would almost certainly have fractured had they been set-in by heavy cold-hammering, it seems that the Bronze Age smith, at least in this instance, knew when to resort to hot working of his metal. It the case of section C, the metal appears to be good and clean and no major defects were observed. Corrosion upon the exterior surfaces has been very slight, with extremely little penetration. A substantial amount of alpha-delta eutectoid is present in the section. An unusual feature of this fairly large section is the considerable amount of redeposited copper which appears. In fact, nearly the whole section shows a network of fairly large pools of copper. So far as one can observe, corrosion is not associated with the copper in this metal.

Examination—Etched

Upon etching the cutting-edge section, a structure of small twinned crystals is seen and no slip banding was observed in these crystals. Throughout the section examined the grain size remains rather small. Only very slight relics of dendritic shading could be seen, and the metal of this section may be approaching uniformity of composition. As previously mentioned, the alpha-delta eutectoid has received some plastic deformation in the region of the cutting edge which would indicate local hot working at this point. Hardness determination gave values of 180 HV_5 at the point, and 116 HV_5 in the mass of the metal. The hardness at 180 at the point is unexpectedly high, but, owing to the presence of appreciable delta phase, the hardness values quoted cannot be interpreted as a measure of work-hardening alone. However, the cutting edge has been work-hardened.

Concerning the flange section, the structure revealed upon etching was similar to that of the cutting edge section, but the relics of dendritic shading tend to be slightly more marked. No slip banding of the crystals was observed and the metal has at some time been hot-worked. The reason for this working was probably not in order to raise the flanges by forging, but to bend them inwards in order to embrace a knee-shaft, so obtaining a secure hafting of the palstave. Hardness determinations at three positions around the flange gave values of 130, 122, and 120 HV_5. In the median web, well away from the flange, hardness descended to 106 HV_5. From these figures it is clear that the edge of the flange has been slightly work-hardened, while the mass of the metal is in soft condition. The most striking feature of section C is the network of redeposited copper which covers most of the interior area of the specimen. A considerable quantity of alpha-delta eutectoid is seen and in the region occupied by the copper the delta would appear to be debased. Throughout the section rather small twinned crystals occur, and these crystals are not slip banded. No sign of the original cast structure could be detected, and it would appear that the metal may approach uniformity in composition. It may be said that the metal of section C has been worked and well annealed, and finally left in the annealed condition.

To sum up, this palstave shows a number of interesting features. It appears to have been thoroughly annealed all over; in each of the sections examined, which were at quite widely separated distances, it was found that the casting has been mechanically worked. The cutting edge of the blade has been appreciably work-hardened. The implement has been subjected to an unusual amount of heating and working and, in places, hot-working has been resorted to. In the sections examined the metal was found to be of quite good quality. In section C only, a considerable amount of redeposited copper was observed. This section is 45 mm from the cutting edge of the blade, and here the casting is substantial, being 10 mm thick.

(5) NEWBURY MUSEUM No. OA. 264.

From near Newbury, Berkshire, England

This is a heavy palstave which is in good condition, with the exception that a small piece of the widely splayed blade has been broken off at one side, apparently in antiquity. The implement is well-shaped and the patination is in good condition. The blade carries a very slight central decorative rib. Under visual examination there is little sign of corrosion attack and in places the cutting edge is still very sharp. The palstave clearly gives the impression of being a casting from a bi-valve mould, the deep flanges and well defined stop ridges being cast in one with the rest of the implement. At their deepest position the flanges rise to 10 mm above the median web, and have a thickness of about 5 mm where they merge into the web, tapering off to a thickness of approximately 2.5 mm at the tip. The total length of the palstave is 171 mm, and the width over the splayed blade was originally about 75 mm. Three sections were taken for metallographic examination, one through the cutting edge of the blade and another (section B) from the side of the blade 50 mm from the cutting edge. Here, the metal is 12 mm thick and the section is well removed from the working zone of the cutting edge. Finally, section C was taken through one flange, and at about its mid-length.

An appreciable quantity of zinc will be noted in the analysis. This is unusual in a Bronze Age metal but is not unique.

Examination—Unetched

Examination of the cutting edge section showed the metal to be clean and sound. A network of very small spots was observed which may be due to lead or to minor porosity. In three positions penetrative attack is severe, but otherwise the specimen has suffered little from corrosion. Throughout the section a considerable quantity of alpha-delta eutectoid was seen. Examination of section B showed the characteristics of the metal to be similar to those of the cutting-edge sample. In general, in section B penetrative corrosion has been very slight, although over a short distance upon one side of the specimen there has been corrosion attack, and here uncorroded alpha-delta eutectoid is seen embedded in the corrosion products. Again, throughout this section a considerable quantity of alpha-delta eutectoid is present. In the case of Section C, examination showed the metal to be excellent and without apparent defects; the patination is very thin and there has been but little corrosion attack. In places, there has been some uniform corrosion, and hence uncorroded alpha-delta eutectoid can be seen embedded in the thin layer of corrosion products. Throughout the section, alpha-delta eutectoid is seen.

Examination—Etched

Upon etching the cutting edge section, a structure of equi-axed twinned crystals was revealed, the smallest crystals being found in the more highly worked zone of the cutting edge with grain size increasing as the mass of the metal is entered. It is clear that the metal has been quite well worked and annealed, and the microstructure would suggest that the metal was finally left in annealed condition. However, hardness determinations gave an unexpected result, since the hardness at the point of the cutting edge proved to be no less than 201 HV_5 and in the mass of the metal remote from the cutting edge the figure was 164 HV_5. However owing to the presence of appreciable delta phase, the hardness values quoted cannot be interpreted as a measure of work-hardening alone. However, the metal has been appreciably work-hardened. Near the cutting edge a long and fine crack was noticed which is most likely a forging crack occasioned by severe cold hammering at the point.

Upon etching section B, taken from the side of the blade 50 mm from the cutting edge, it was found that much of the metal had been worked and annealed. In the mass of the metal, relics of the cast structure are observed, but at the angle of the section, and along the sides, the structure consists of equi-axed twinned crystals of comparable size to those noticed in the mass of the metal of the cutting edge sample. At this position in section B the casting has been subjected to plastic deformation, probably by cold work, followed by heating to above the recrystallization temperature, and the metal has been left apparently in unhardened state.

Upon etching section C, taken at mid-length of one of the flanges, the partially annealed structure of the casting was revealed throughout the whole area. In one isolated position at the tip of the flange two or three twinned crystals could just be seen indicating working and that here, the recrystallization temperature had been reached. These few twins were no doubt caused by some accidental blows during fabrication of the palstave. However, it is clear that no hammering or forging of any kind has been applied to the flange examined.

The conclusion is that the metal of the cutting edge section has been well worked and annealed, and the point was afterwards work-hardened to a very appreciable extent. In section B it was again found that much of the metal had been worked and annealed. Finally, in the case of section C the metal has been partially annealed but was unworked. It is clear that the whole implement has been more or less uniformly heated, and working was by no means restricted to the region of the cutting edge, since there is evidence of mechanical working so far away as 50 mm from the cutting edge.

In the three sections examined the quality of the metal appeared to be excellent.

(6) NEWBURY MUSEUM No. OA. 63.

From Weybridge, Surrey, England

This is a small and well made palstave which was cast in a bi-valve mould, since the original casting flashes are clearly to be seen. The stop-ridges are deep and almost amount to pockets, while the side wings or flanges are also pronounced. It is clear that both the stop-ridges and the wings have been cast as a whole with the rest of the palstave. Indeed, from their contours and dimensions, it would have been impossible to raise the stop-ridges and wings by forging. The patination is of a bronze colour and, under visual inspection, the condition of the palstave appears to be excellent and with hardly any corrosion attack. The blade is strongly splayed and the cutting-edge is sharp and in very good condition; in cross-section the edge is slender and well proportioned for the purpose of a cutting tool. Down the centre of the blade there is a small decorative ridge, and both sides of the blade carry slight flanges which are probably more for decorative purposes than to add strength to the blade. At their mid-length the wings stand up about 9 mm above the median web; at their tips the wings are slender, approximately 1 mm thick, but tapering to about 3. 5 mm at the root where they merge into the median web. The total length of the palstave is approximately 125 mm, and the width over the splayed blade is 62. 5 mm

For metallographic examination four sections were removed. One section was taken through the cutting edge of the blade, and another (section B) trepanned out of the median web approximately 35 mm from the butt-end. Here, the metal of the web is 8 mm thick. Section C was removed from the side of the blade 35 mm from the cutting edge. This section takes in one of the slight flanges which follow the side of the blade. Section D is through the middle or deepest portion of one of the wings.

Examination—Unetched

The metal of the cutting-edge section is very clean and sound; indeed it may be said to appear to be of excellent quality. In the polished section the only feature noticed was a network of small inclusions which may be of slag origin. In the region of the cutting edge, slag inclusions have been plastically deformed and drawn out into stringers, suggesting that at some stage in its history the metal has been hot-worked. In this section alpha-delta eutectoid was not observed.

In section B, taken from the median web, the metal is also clean and sound, and remarkably free from corrosion attack. The same network of small inclusions, commented upon in the case of the cutting-edge section, was observed. It is difficult to say what these inclusions are, but possibly they are of slaggy origin. At one of the exterior surfaces there has been slight corrosion attack and here, seven or eight small islands of redeposited copper were observed; this copper appears associated with corrosion products. Alpha-delta eutectoid appears to have been almost absorbed, since only four or five very small islands of the eutectoid were seen in the whole of the section.

In section C, except for a network of very small inclusions and a very little minor porosity in one place, the metal is clean and sound in appearance. Patination on the exterior surfaces is exceedingly thin and to all intents and purposes corrosion attack is absent. A few isolated islands of alpha-delta eutectoid, much modified in outline, were seen.

In the case of section D, taken from one wing, the polished metal is of similar appearance to that of section C, but no alpha-delta eutectoid was seen. Upon one side of the specimen, very slight corrosion attack has taken place and here, in one or two places minute pools and filaments of, apparently, redeposited copper were observed.

Examination—Etched

Upon etching the cutting-edge section with alcoholic ferric chloride the structure revealed is of small equi-axed twinned crystals characteristic of an alpha-phase solid solution. Throughout the section examined many of the crystals show strain banding, indicating that the metal has been cold worked as a terminal operation. The alpha-delta eutectoid has apparently been absorbed and the metal probably was subjected to considerable working, both hot and cold. Little difference in grain size was noticed between the zone of the cutting edge and that of the mass of the metal. Within a normal etching time no relics of dendritic shading appeared in this section and the metal probably approaches uniformity in composition. Hardness determinations confirm that the cutting-edge had been hardened to a high degree, a reading of 200 HV_5 being recorded at the point. In the mass of the metal remote from the point the hardness value descended to 150 HV_5.

Upon etching section B, only the annealed structure of the original casting was seen. At this point the casting, although heated, has not been worked and no twinned crystals were present in any part of the section examined. Since section B is at the butt-end of the palstave and thus far removed from the cutting-edge, the heating to which this implement was subjected must have been of a general nature, and was not confined to the region of the working edge.

In the case of section C, from the side of the blade, it was found that at, and adjacent to, the slight flange previously mentioned recrystallization had taken place; equi-axed twinned crystals of medium size were seen, not slip-banded. Here, the metal had been worked and left in annealed conditions. As the mass of the metal is entered, the annealed structure of the casting appears; coring seems to have been eliminated and the metal has been well annealed. It must have been subjected to moderate heating for a considerable period, or to heating at higher temperature for a shorter time. Little alpha-delta eutectoid was seen.

In section D, taken through one of the wings, within a small localized area at the tip of the flange recrystallization has taken place and twinned crystals, some of greater than average size, appear. In general these crystals are not slip-banded. However, at the extreme point the section has been slightly flattened, and here some slip-banded crystals do appear, but this could be due to accidental damage or to rough treatment. In all the rest of the section only the annealed structure of the original casting was seen; coring was not detected, and the metal has received considerable annealing but it was not worked. In this section no alpha-delta eutectoid was seen.

The four sections examined show that the cutting edge of the palstave has been thoroughly worked and annealed and, as a final operation, it has been work-hardened to an unusually high degree. At a distance of 35 mm from the cutting-edge there is evidence that some mechanical working has been applied to this part of the blade. For the section taken from the median web it was found that the metal had been annealed, but it had not received any mechanical working. Practically the same may be said of the metal taken from one of the wings. Not only was this palstave given a general heating, but the heating was unusually thorough or, at unusually high temperature. Working was not confined to the cutting edge, but extended to a distance of at least 35 mm from the edge and hot as well as cold working was resorted to.

The quality of the metal in the various sections examined appeared to be very good. The palstave is also of note in that redeposited copper appeared in one of the exterior surfaces of the section taken from the median web. Minute pools and filaments of copper were also seen in section D, taken from one wing. In both cases, the copper is found in unworked regions of the metal, but in places where some corrosion has taken place.

(7) NEWBURY MUSEUM No. OA. 351

From Ireland

This implement is a heavy palstave with deep but straight wings or flanges which would withdraw from a conventional bi-valve mould; the stop-ridges are very slight and would appear to be merely symbolic. The end of the butt has been fractured, and here a large blow-hole or cavity is to be seen on the line of the fracture. Otherwise, the palstave is in excellent condition, with its cutting edge in a good state of preservation and reasonably sharp. Patination is of a bronze colour, and there is little visual evidence of corrosion attack. The median web is clearly designed to resist the thrust upon a haft, since it tapers from 5 mm at the butt to 13. 5 mm where the web meets the blade. The wings are deep, rising above the web by 15 mm in the case of one wing and 13 mm for the other. The total length is 159 mm, and the width over the splayed blade is 64. 5 mm.

Three sections were removed for metallographic examination. One from the cutting-edge of the blade, and one (section B) from the side of the blade 65 mm from the cutting-edge; this section takes in the full thickness of the blade, which is here 14. 5 mm. Finally, section C was taken through one of the wings. Here, the thickness at the root of the wing is approximately 4 mm, tapering off to about 1. 5 mm at the tip.

Examination—Unetched

Along the sides of the cutting-edge specimen were found intercrystalline penetration and corrosion upon crystallographic planes. The cutting edge itself is of clean metal, while in other parts of the section the metal may be described as of fair to poor quality; in the region of the cutting edge, but not extending to the actual point, there is a long crack. Throughout the section examined there is a network of small spots, probably minor porosity, and a considerable quantity of lead. Alpha-delta eutectoid is not observed, and non-metallic inclusions are very small in size; any inclusions seen appear to be undisturbed and provide little information as to the mode of fabrication of the artifact. A considerable number of small pools of redeposited copper can be seen, and these pools of copper have the appearance of being associated with areas of penetrative corrosion.

In the case of section B, along the edges of the specimen there is some intercrystalline penetration and, in places, corrosion upon crystallographic planes. However, corrosion attack has been slight and the mass of the metal is sound and practically free from porosity. Discrete particles of lead are seen. Along the edges of the specimen, but not within the mass of the metal, a considerable number of small pools of redeposited copper are present. For section C, taken through one of the wings, the same remarks as for section B apply for the examination of the polished metal. Also, the same distribution of very small pools of redeposited copper is observed along the edges of the specimen. Again, this redeposited copper is not seen within the mass of the metal.

Examination—Etched

Upon etching the cutting-edge section, extremely small crystals can be seen outlined by the intercrystalline penetrative corrosion along the edges of the specimen. In the mass of the metal recrystallization has not taken place, and here strong relics of the original cast dendritic structure predominate. It would appear that, after the palstave was cast, the cutting-edge was hammered and then heated to the recrystallization temperature. However, the heating and working were of limited nature since in the interior of the section the metal remains substantially in the cast state. Hardness figures taken upon the cutting-edge section showed that some work-hardening has been applied to the cutting-edge as a terminal operation; the hardness at the point was found to be 152 HV_5, decreasing to 134 HV_5 in the mass of the metal.

Upon etching section B it was seen that a very narrow band of extremely small crystals are outlined by the intercrystalline corrosion attack. In the etched section some very small pools of eutectoid can just be seen. It appears that the exterior surfaces of the specimen have received some slight measure of plastic deformation followed by heating at a low temperature. No recrystallization could be seen in the mass of the metal, which remains substantially in the cast state. Here, the structure is somewhat diffused owing to the heating which the casting has received at this point. Again, in the case of section C the metal is substantially in the cast condition, and recrystallization was not observed. Some diffusion in the structure indicates that the metal has been heated after it was cast. Such heating was at moderate temperature and is quite possibly due to heat transfer from the region of section B. Apparently, the wing has not been mechanically worked.

To sum up for this palstave it may be said that in general in the three sections examined the interior, or mass of the metal, is substantially in the cast condition. After it was cast, the palstave was subjected to a general heating all over. The cutting edge has been worked and some recrystallization has occurred. Also, even so far removed a 65 mm from the cutting edge, the blade has been mechanically worked and recrystallization has occurred. On the other hand, the wing section examined was not mechanically worked, and presumably the butt end of the palstave has not been worked. The cutting edge of the blade has been work-hardened as a terminal operation, 152 HV_5 being recorded at the point. The metal of the cutting-edge section is not of good quality, but in the other two sections the metal appears to be sound. A somewhat unusual feature of this implement is that in all the sections examined small pools of redeposited copper were detected, and all these small pools occurred at, or near to, exterior surfaces of the metal.

(8) NEWBURY MUSEUM No. OA. 227.

From Ireland

This palstave is not looped, but it is provided with side flanges to assist in securing the haft and very deep pockets which form the stop-ridges. It was cast in a bi-valve mould since the casting flashes are clearly to be seen; clay drawbacks must have been used in the mould because the deeply recessed pockets could not have been withdrawn from the mould without the use of separate drawbacks. In this example the moulding technique was not first class, registration of the half moulds was not accurate and the parting lines show irregularity; indeed, the whole implement is roughly made and poorly finished. The blade is considerably splayed and the cutting edge is of quite satisfactory contour to act as a working tool. The cutting edge has apparently received rough use in antiquity and it is badly notched. In colour, the patination varies between chocolate and rather dark green, but appears to be in stable condition. In general the surfaces are rough, suggesting that there has been considerable corrosion attack. Only one of the flanges remain undamaged, the other three all being fractured, and major portions of the metal are missing; this may have been due to rough handling in antiquity, or to defects in the metal leading to fracture when a haft was driven tightly between the flanges. The total length of the palstave is approximately 108 mm, and the width over the splay of the blade is 47 mm.

Four sections were removed for metallographic examination. One section through the cutting edge, and another, (section B) was taken from the side of the blade at a position just below the deep stop-ridge pocket about 60 mm from the cutting edge. Section C was taken from one side of the blade, some 30 mm from the cutting-edge. This section takes in the full thickness of the blade and provides an intermediate position between the cutting edge and section B. Finally, section D has been taken through the only flange which remains undamaged. Here, the flange is about 10 mm in depth with a thickness at the root of about 4 mm. Upon cutting out this section the sample fractured, and the metal can only be described as rotten.

Examination—Unetched

In general, the metal of the cutting edge section is very clean, sound, and without marked defects; it is also remarkably free from non-metallic inclusions. Porosity is absent at the cutting-edge and but very slight in the mass of the metal. Corrosion attack is slight, but in places upon the edges of the section there has been intercrystalline penetration and corrosion upon crystallographic planes. The whole section examined exhibits a large amount of interdendritic alpha-delta eutectoid. Examination of section B shows a considerable amount of porosity and, unlike the cutting-edge metal, it is not generally sound. Corrosion attack along the edges of the specimen has not been unduly severe, but there has been extensive intercrystalline penetrative corrosion. The clean areas of the metal are practically free from non-metallic inclusions of slaggy origin but, in places, there are islands of what appear to be slag-like inclusions, and these would seem to be associated with porosity. Throughout the section a considerable amount of alpha-delta eutectoid is seen. Section C suffers from considerable gas porosity, and the metal cannot be termed sound, but along one side of the specimen there is a band of apparently sound metal and possibly the metal has here been consolidated by hammering. In places upon the exterior surfaces corrosion attack has been marked, and there is considerable intercrystalline penetration. The whole section exhibits a large quantity of alpha-delta eutectoid. Finally, in section D the metal was found to be quite rotten and fractured of its own accord during the cutting out of the sample. Throughout the section there is severe porosity and upon the exterior surfaces corrosion attack has been extremely severe and much uncorroded.

Delta phase is seen embedded in the heavy corrosion products. As in the case of the other sections examined, a large quantity of alpha-delta eutectoid is distributed throughout the section.

Examination—Etched

Upon etching the cutting-edge section a structure of medium-size equi-axed twinned crystals superimposed upon relics of dendritic shading was revealed. As the mass of the metal is entered there is some increase in grain size, but to no marked extent. Sufficient heating and working has not been applied to the cutting-edge section to render the metal uniform in composition. In general, no slip banding or deformation of the crystals was observed and the metal has the appearance of being in annealed condition and, from the microstructure, it would not appear that the cutting-edge has been work-hardened. However, the tip or point of the cutting-edge has been mechanically damaged by rough use, and here some strain-banded and deformed crystals could be seen. Hardness determinations gave 192 HV_5 at the point, and 144 HV_5 in the mass of the metal.

These figures are somewhat unexpected but, owing to the presence of very appreciable delta phase, the hardness values quoted cannot be interpreted as a measure of work-hardening alone. However, it is clear that the metal has been considerably hardened.

Upon etching section B, it was found that the structure in the mass of the metal is that of the annealed casting but, in a band along the edge of the specimen recrystallization has taken place and twinned crystals, which are not slip banded, are seen. Hence, while the body of the metal is substantially unworked but annealed, the edges of the specimen have received some plastic deformation followed by heating to the recrystallization temperature, and the metal has been left apparently in annealed condition. Upon etching section C, it was found that upon the edge and one side of the section there is a considerable band of rather small equi-axed twinned crystals, while in the mass of the metal the annealed structure of the casting appears. In the annealed structure coring was not seen. The metal of this section has been considerably heated and the greater part of the exterior surface has been plastically deformed, probably by cold work, and then heated to recrystallization temperature. Slip banding was not seen in the twinned crystals and the metal has apparently been left in annealed state.

Upon etching section D, taken through one of the flanges, the structure revealed is substantially that of the original casting in annealed state. Coring was not observed and the metal has evidentally been subjected to considerable heating. No evidence was found to indicate that this flange metal has been worked. Indeed, it would have been hardly possible to work such unsound metal.

To sum up for this implement it may be said that it has been heated throughout and annealed to greater or less extent. Recrystallization has occurred in the cutting-edge section, which has been well worked, and the point has finally been work-hardened to a very appreciable extent. In the sections taken from the blade at 30 and 60 mm above the cutting-edge, it was found that the exterior surfaces had been worked, and some recrystallization had taken place. Hence, mechanical working (hammering) has by no means been confined to the region of the cutting edge, but extends far up the blade. It was found that the metal of the flange section examined was unworked, and it is highly probable that the other flanges were also left in unworked condition. Concerning the general quality of the bronze, in the cutting-edge section it appears to be very good, and this is probably due to much consolidation by forging or hammering. In the other two worked sections of the blade the metal is not sound, and it is significant that working (hammering) is here much less than in the case of the cutting-edge section. Finally, in the wing material the metal is quite rotten and here it is unworked.

(9) NEWBURY MUSEUM 1962-12.

England

This palstave is provided with a single side loop, a more or less straight-sided blade, and deep pockets which form stop-ridges. The patination is of a dark green colour which is in good condition and appears to be stable. A large blow-hole, or possibly a casting shrinkage cavity, is noted in the butt, and also some small holes elsewhere. The cutting-edge is slightly damaged by rough use but, under visual inspection the palstave appears to be sound and in good condition.

The total length is 167 mm, and the width over the blade is 42 mm. Three sections were removed for metallographic examination: as usual, one section from the cutting-edge of the blade, and a control section B from the thick part of the blade some 70 mm from the cutting edge, where the cross-section of the blade is approximately 22 mm wide and 18 mm thick. At this point one would expect the metal to be unworked, since it includes a median rib which has the appearance of being a part of the whole casting. As a further control, section C was taken through one flange just above the stop-ridges or pockets. The flanges are clearly a feature of the solid casting, so here again one may expect to find unworked metal.

Examination—Unetched

Examination of the polished surface of the cutting-edge section showed that at the cutting edge and along the sides of the specimen there has been some intercrystalline penetration and corrosion on crystallographic planes, and some stress-corrosion cracking was also seen, but, on the whole, corrosion attack is slight. Over the whole section examined is a network of small globules of dove-grey colour which may be non-metallic inclusions of slag origin. In general, the mass of the metal is sound. Alpha-delta eutectoid was not observed. In the case of section B, except for a certain amount of unimportant and isolated porosity, the metal is relatively sound. Corrosion attack upon the edges of the specimen has not been very severe, although in places intercrystalline penetration is marked. As in the cutting-edge section, a similar network of small inclusions was observed. Only a few small and isolated pools of alpha-delta eutectoid were seen. Of section C it may be said that the metal is relatively clean and sound and very little porosity was observed. Corrosion attack upon the exterior surfaces of this flange section has not been severe, although in places there is a certain amount of intercrystalline penetration. Similar small inclusions, possibly of non-metallic nature, to those mentioned for the other sections were present. As in the case of section B, a number of small and isolated pools of alpha-delta eutectoid were seen.

Examination—Etched

Upon etching the cutting-edge section with alcoholic ferric chloride, the general structure revealed is of strain-banded twinned crystals superimposed upon a rather dark background, possibly the very diffused relics of dendritic shading. Throughout the section examined strain banding of the crystals is prevalent; at the cutting edge the crystals are small, but there is a marked increase of grain size as the mass of the metal is entered. The metal has been plastically deformed, probably by cold work, followed by heating at above the recrystallization temperature. While not homogenized, it has probably received considerable heat treatment, the final operation being a relatively light cold hammering. The cutting-edge has been work-hardened, no doubt intentionally so, the hardness of the edge being approximately 153 HV_5, descending to 129 HV_5 in the mass of the metal remote from the edge.

Upon etching Section B a structure of equi-axed twinned crystals was seen over a large area of the section examined, in particular, at the angle of the section and along its sides. In the mass of the metal remote from the exterior surfaces the twinned crystals shade off, and the annealed structure of the original casting appears; coring seems to have been eliminated and the metal has the appearance of approaching a uniform composition. In general, slip banding was not observed in the twinned crystals and the metal has been left in a fully annealed condition. In this section the metal of the palstave has been worked and well annealed (the annealing temperature was probably in excess of 650°C), and it may be noted that at this point in the casting the most intensive working has been concentrated at the angle of the section where it may be that the angle has been dressed by hammering.

In the case of Section C (the flange section) etching revealed an annealed structure of the casting. The metal has been quite well annealed since coring appears to have been eliminated. Although at one isolated position twinned crystals were observed (such isolated twins cannot here be relied upon since they could easily be caused by a few accidental blows during fabrication), it may safely be said that the metal in the flange, although annealed, had not been worked.

To sum up for this palstave, the cutting-edge has received considerable heat-treatment, working, and has been quite considerably hardened. At the considerable distance of 70 mm from the edge of the blade the casting has been well annealed and has certainly received some mechanical working. Finally, still further away from the blade the flange metal was found to be well annealed but unworked. It is clear that the whole palstave has been heated and the temperature and time of heating has been sufficient to anneal the whole casting. The treatment accorded to the cutting edge is what may be expected, so also is the unworked metal in the flange section, but the mechanical working of section B 70 mm from the edge of the blade is worthy of note, and one would think unnecessary in the case of a casting of this nature.

(10) NEWBURY MUSEUM No. OA. 325.

From Co. Antrim, Ireland

This palstave is extremely badly proportioned, clumsy, and very roughly finished. It is clearly a casting from a bi-valve mould and, in places, relics of the original casting flashes can be seen. Although no doubt there has been corrosion attack, under visual inspection the chocolate-coloured patination appears to be good and in stable condition. The cutting edge of the blade is sharp and in a good state of preservation; the blade is well splayed but it is very small in comparison with the rest of the implement. Stop-ridges are formed by two deep pockets, and six (three on each side) very roughly executed decorative ribs run down the blade below the pockets. This median web is wedge-shaped, 7 mm thick at the butt end, increasing to 15 mm at the stop-ridge pockets. The web has small side flanges but these extend to but little more than half-way towards the butt. The total length of the palstave is 147 mm, and the width over the blade is 43 mm.

Three sections were taken for metallographic examination. One was from the cutting-edge of the blade and another (section B) has a trepanned section taken from the median web approximately 26 mm from the butt end of the palstave. Section C has been taken from the side of the blade just below the loop, some 47 mm from the cutting edge.

Examination—Unetched

Upon examination of the polished surface of the cutting-edge section, the metal appears to be of good quality, and the only defects seem to be those due to corrosion attack. One edge of the section is clean and almost free from corrosion attack, at the cutting edge, and upon the other edge of the specimen there has been corrosion attack which is relatively severe in places; from one edge there is a long branch of penetrative corrosion. Porosity and non-metallic inclusions are almost absent. An unusually large amount of alpha-delta eutectoid is dispersed throughout the section, and this eutectoid appears to be undisturbed.

In the case of section B (taken from the median web), some corrosion attack and also porosity were observed. Otherwise, the metal is reasonably sound, apart from a network of inclusions which do not have the appearance of the non-metallic inclusions of slaggy origin so often found in the ancient bronzes. In this section no alpha-delta eutectoid could be seen, and so there would appear to have been a segregation of the eutectoid towards the cutting-edge part of the casting.

In section C the metal is fairly sound but the area appears to be covered with micro porosity, and there are also a few small blow-holes. Also, the same network of inclusions observed in the case of section B was seen; the nature of these inclusions is not clear. Upon the exterior surfaces of the metal, corrosion attack has been but slight. In this section alpha-delta eutectoid was not observed. All round the exterior surfaces of the bronze small pools of redeposited copper can be seen and the major part of this copper is observed in areas of intercrystalline penetrative corrosion. In the mass of the metal redeposited copper was not seen, and the copper appears to be confined to the exterior surfaces of the metal. Only in this section was redeposited copper noticed.

Examination—Etched

Considerable difficulty was experienced in etching the material of this palstave. The metal appears to be decidedly inert to alcoholic ferric chloride or to ammonia hydrogen peroxide as etching reagents, and satisfactory photography was not attained. Upon etching the cutting-edge section with alcoholic ferric chloride a structure of small equi-axed twinned crystals was revealed, and but little increase in grain size was observed in the mass of the metal remote from the thin cutting-edge. Under relatively high power, some strain banding could be seen in the crystals adjacent to the cutting-edge itself. Coring was not detected, and the metal has been annealed and, in general, left in annealed condition, although some action was taken to harden the cutting edge by local hammering at the extreme point. In this section an unusually large quantity, even for a bronze the analysis of which shows 11% of tin, of alpha-delta eutectoid is present. It appears that there has been an unusual segregation of the eutectoid since in the two other sections examined it was not seen. It is also noted that the content of iron in the alloy is 0.11%; this is much higher than is normal in the prehistoric bronzes, in which the elimation of iron is often very complete.

Upon etching section B it was found that the structure of the metal is substantially that of the original casting, no recrystallisation was observed, and any heating was insufficient to alter the cast structure to any marked extent. At this point in the median web close to the butt-end of the palstave the metal has not been worked.

In section C the partially annealed structure of the original casting was seen in the mass of the metal. With difficulty, around the edge of the section, minute twinned crystals could be seen and in many places these crystals are slip-banded. It appears probable that the metal has had a low-temperature anneal and that the metal around the exterior of the section has been plastically deformed, followed by heating to the recrystallization temperature, since recrystallization has just commenced. As a final operation the surface has been cold-hammered to some extent.

In the case of this implement the major heating and working has been applied to the cutting-edge, but 47 mm above this point the blade has been heated to recrystallization temperature, so that heating was of a general nature, and was not confined to the edge of the blade. The cutting edge has been work-hardened and the blade has also been cold-hammered 47 mm above the cutting edge. In this palstave there are two unusual features: first, the apparent concentration of the delta phase in the cutting-edge section, and secondly, the near surface appearance of redeposited copper in section C alone.

(11) NEWBURY MUSEUM No. OA. 331.

From Ireland

This palstave has a well splayed blade and deep side wings or flanges; it is cast with a very marked stop-ridge or rather pocket. This pocket is steeply recessed, so that the casting might be difficult to withdraw from a conventional bi-valve mould. Hence, a drawback may have been allowed for in the moulding, since the implement is clearly a casting from a bi-valve mould. The patination appears to be good and in a stable condition. The cutting edge of the blade is of fine section and in quite good condition, except for one place where it has received recent accidental damage. At the winged end of the palstave, and over some portion of the blade, the casting is highly defective, for visual inspection alone shows many large and small blow-holes, and the end of the median web has been fractured through a series of holes and apparent casting defects. The median web between the flanges is only 4 mm thick. The side flanges or wings are thin but deep; at the root, the wings have a thickness of about 4 mm, tapering off to only 1-1.5 mm at the edges. The depth of the wings is approximately 13 mm at their deepest point. The length of the palstave is approximately 120 mm, and the width over the splayed blade is 58.5 mm.

Three sections were removed for metallographic examination: one from the cutting edge, and another (section B) from the side of the blade approximately 55 mm from the cutting edge, where the metal of the blade is 14 mm thick. The third sample (section C) was taken through one wing or flange.

Examination-Unetched

Examination of the polished metal in the cutting-edge section revealed some isolated porosity. The cutting edge and sides of the specimen are remarkably free from corrosion attack. There is a small longitudinal crack at the cutting edge, and another adjacent to the edge. These cracks could have originated as interdendritic porosity (extending in some instances to the surface), and lengthened by a forging operation. Alpha-delta eutectoid is dispersed throughout the section examined. The metal would be quite serviceable and may be described as of fair quality.

In Section B considerable areas of the metal are unsound, containing porosity and several large voids. Corrosion attack upon the exterior surfaces has not been severe. In fact, one edge of the specimen is sharp and remarkably well preserved. Alpha-delta eutectoid is dispersed throughout the section, and the metal poured was clean, since non-metallic inclusions of slaggy origin was not detected.

In the case of Section C (taken through one of the wings), while not absolutely unsound, the metal exhibits considerable gas porosity throughout the area examined. Otherwise, the characteristics of the metal are similar to those of Section B.

Examination—Etched

For a palstave, the cutting-edge section is rather unusual in that it appears to have received but very moderate heating and working. Upon etching, at and adjacent to the cutting edge, a structure of small equi-axed twinned crystals superimposed upon relics of residual coring could be seen. Then, in the mass of metal remote from the cutting edge the structure becomes substantially a cast one and no recrystallization is seen.

In the region of the cutting-edge no slip banding of the small crystals is observed. The metal has been subjected to some plastic deformation, probably by cold work, and, at least in the region of the cutting edge, has been heated to the recrystallization temperature. The heating was probably at low temperature, possibly not more than in the region of 400°C. Although slip bands were not detected in the small twinned crystals, the cutting edge has been work-hardened. Here, the not inconsiderable figure of HV_5 174 was recorded and, remote from the cutting edge, the hardness value descended to 109 HV_5.

Upon etching Section B it is seen that the metal throughout this section is substantially in the cast state, although it has been heated and the cast sub-structure shows slight diffusion. Over a narrow band along the exterior surfaces of the metal recrystallization has occurred, rather small twinned crystals which are not slip-banded, being observed. It appears that the exterior of the metal has been very lightly worked followed by heating to recrystallization temperature. The heating was probably at low temperature, or of short duration, in view of the fact that the general mass of the metal remains substantially in the cast condition and cannot be said to have been subjected to any prolonged anneal.

In Section C the metal again is found to be substantially in the cast condition, but it has received some measure of heating. The general structure is the same as that of section B, but with the exception that no recrystallization was observed. The wing of the palstave does not appear to have been mechanically worked in any way.

For the three sections examined the conclusions are that the interior, or mass of the metal, is substantially in the cast state; however, after it was cast the palstave was subjected to a general heating. The cutting edge has been worked and some recrystallization has occurred at the point, which has also been work-hardened to an appreciable extent. As far as 55 mm from the cutting-edge, the surface of the blade has been lightly worked and recrystallization has occurred over a narrow band at the surface. The metal of the flange has not been worked, and remains substantially in the cast state, although it has been subjected to some heating. It may be said that, as a whole, the metal in this implement is not up to standard and is of rather poor quality.

CONCLUSIONS

From these palstaves a certain pattern of fabrication does seem to emerge. For instance, all the implements examined have been subjected to a general overall heating after they were cast. They were not just locally heated and worked at the cutting-edges of the blades alone. Again, it was found that in all cases the cutting edges of the blades have been heated and worked and, as a final operation, the cutting edge has been work-hardened by cold-hammering in order to harden it. In some of the specimens the blade has been hardened to a remarkable extent. Apparently the Bronze Age smith was quite familiar with this operation which, in the case of the relatively high-tin bronzes, was one which called for considerable skill in order to avoid edge-cracking of the material during the final stages of hammering.

From the stone and metal moulds found it is known that palstaves were usually cast in accurately made moulds which would produce a casting very close to the desired finished shape, and it would therefore be expected that normal practice would be to dress up the edge of the blade by forging, if necessary, and then to work-harden it. Apart from this, all that should be necessary is to fettle and smooth the casting by grinding, since metal cutting files were not available in the Bronze Age. However, this simple technique was by no means always followed, because it has been found that the whole implement has been annealed and, in some instances, that hammering has been extended far beyond the region necessary for working the cutting edge of the blade. Two of the specimens, OA. 93 and OA. 322, are remarkable in that they appear to have been hammered all over. All the other palstaves have been hammered on the blades at considerable distances above the cutting-edge, the distances varying from at least 35 mm to as much as 75 mm. In connection with such working it is important to note the winged axe (transitional to the palstave), examined by Raistrick and Smythe and commented upon by Tylecote(1), which has also been annealed followed by extensive hammering of the casting. Today it is known that an annealed metal is usually much less brittle than a cast metal of the same composition, and also that hammering is advantageous in consolidating the metal. Again, Tylecote has pointed out(2) that it was common practice to increase the strength of a cast alloy by working. Is it not possible that the Bronze Age smith discovered these properties during the course of his long experience?

In archaeological literature it has sometimes been postulated that bronze was never hot-worked during prehistoric times. No doubt, in view of the limited equipment of tools available, it was more comfortable to work with cycles of annealing and cold-hammering, and the major production may well have been so carried out. However, hot-working was resorted to in the case of palstaves OA. 63, OA. 93, and OA. 322, and quite possibly other specimens may also have been hot-worked since it is not always possible to detect this feature from the microstructure.

For the examination of the eleven palstaves a total of thirty-three samples were removed, and in only six of these sections was bad or unsound metal found, i.e., in about 18% of the total number of specimens taken. This is not a bad average and supports the suggestion that, in general, palstave metal is of better quality than that found in socketed axes. Socketed axes are of later date and, are of course cored castings, as against the solid-cast palstaves.

The zinc content in OA. 264 calls for some comment. Zinc is rare in early bronzes and is often thought to be an indication of a forgery. A recent examination of some decorated flat axes of alleged British origin(3) which included two thought to be from Glencar, Sligo, showed that these were very likely to be forgeries, especially since the flat axe had a very pronounced medial parting line which is unheard of in an ancient flat axe. How-

Composition and Properties of Palstaves (wt. %)

	1	2	3	4	5	6	7	8	9	10(LBA)	11
	OA 265	OA 324	OA 93	OA 322	OA 264	OA 63	OA 351	OA 227	1962-12	OA 325	OA 331
	Bagnor Berks	Weybridge Surrey	Ireland	Ireland	Newbury Berks	Weybridge Surrey	Ireland	Ireland	England	Co. Antrim Ireland	Scotland
Cu	90. 9	79. 8	88. 3	93. 9	81	90. 0	84. 3	88. 2	90. 8	87. 8	88. 1
Sn	7. 7	8. 5	11. 5	5. 8	7. 8	9. 3	7. 7	10. 5	8. 8	11. 1	10. 1
Pb	0. 08	10. 2	n.d.	0. 04	1. 1	0. 09	6. 3	0. 19	0. 15	0. 07	0. 56
As	0. 75	n.d.	n.d.	n.d.	0. 59	n.d.	0. 62	0. 34	n.d.	0. 75	0. 75
Sb	n.d.	0. 70	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ni	0. 30	0. 35	0. 038	n.d.	0. 43	0. 5	0. 35	0. 49	0. 23	0. 27	0. 48
Bi	< 0. 01	0. 01	< 0. 01	<0. 01	<0. 01	<0. 01	<0. 01	<0. 01	<0. 01	<0. 01	<0. 01
Fe	0. 084	0. 16	0. 016	0. 017	0. 36	0. 054	0. 13	0. 097	0. 039	0. 11	n.d.
Zn	0. 083	n.d.	n.d.	n.d.	8. 6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ag	0. 055	0. 28	0. 018	0. 18	0. 064	0. 025	0. 03	0. 03	0. 038	0. 05	0. 062
An	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Hardness HV 5	161-239	—	142-206	106-180	164-201	150-200	134-152	144-192	129-153	Segregated	109-174
Annealed or Hot worked	Yes	Yes	Yes	Yes	Yes	Yes	Yes (some)	Yes	Yes	Some	Some
Cold work	Yes	Yes	Yes	Yes	Yes	Yes	Yes	(?)	Yes	Yes	Yes

Note: n.d. = not detected.

ever, the Newbury example is not unique and, furthermore, a detailed examination shows that all the other properties are in keeping with its supposed archaeological date. There are other examples of unquestioned authenticity such as the LBA ring from the Taunton Workhouse Hoard (7. 5% Zn) and the E. I. A. armlets from Aboyne, Aberdeenshire, which contained 1. 44 and 9. 13% respectively.

O'Neill(4) reports the analysis of a piece of metal of the E.I.A. from Merthyr Mawr Warren, which was found to contain 3. 6% Zn and only a trace of tin, so there is quite a lot of evidence for zinc in bronzes of the later prehistoric period both from this country and from the Middle East. Perhaps the earliest zinc-containing specimen is a flat axe from Cornwall, which contained 2. 2% Zn. Zinc-containing copper ores are quite common and usually contain lead also: one such is being worked at Tynagh in Galway now(5). A good deal of the zinc would go into the slag during primitive copper smelting, and Davies(6) found a fayalite slag in Wales containing 14. 5% Zn. However, one would expect some zinc from high-zinc ores to go into the copper. One cannot, therefore, say that a B.A. artifact is a forgery on the evidence of its zinc content alone; the specimen here is undoubtedly genuine.

It will also be noticed that two of the specimens (both M.B.A.) had substantial amounts of lead which were very likely to have been added. One of these is South-Eastern in origin and, therefore, seems to be an exception to the general trend found by Brown and Blin-Stoyle(7) that lead additions came into South-Eastern England about 1000 B.C. and marked the transition from the Middle to the Late Bronze Age. The second leaded specimen has an Irish provenance and it is just possible that 6. 3% of lead could be derived by smelting some of the highly leaded ores such as those from Conlig, Co. Down(8). There is, after all, a thin-butted axe from Cornwall containing 8. 2% Pb.

ACKNOWLEDGEMENTS

Sincere thanks are due to the Director, Research Laboratory for Archaeology and the History of Art, Oxford, for the spectrographic analyses, and to Mr. Ian Macphail (Harwell), and Mr. J. G. Tweeddale (Imperial College), for the Vickers hardness tests.

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Some vitrified products of non-metallurgical significance

R. T. EVANS and R. F. TYLECOTE*

A great deal of vitrified material from archaeological sites comes into the hands of metallurgists because it is often thought to be slag from metal-working operations. One example of this was some vitrified material, light in colour and of low density, from the Iron Age site at Hawk's Hill in Surrey.

Zeuner(1) has already discussed some of the possible origins of this sort of material. The most likely possibilities in the British Isles are:

(a) Glass slag.

(b) Vitrified wood ash.

(c) Vitrified seaweed ash.

(d) Vitrified cow-dung.

(e) Burnt hay stack.

Dried cow-dung was, and still is, used as a fuel in some parts of the world; Zeuner analysed some vitrified material from a heap at Kudatini in India which was undoubtedly cow-dung.(1)

Seaweed ash is made in the Orkneys and Shetlands and is known as 'cramp'.

Typical Characteristics for Identification

First, metallurgical slags from early iron and copper working are high in iron and tend to be ferrous silicates, approximating in composition to $2\ FeO.SiO_2$. Some of these may be diluted with furnace lining, but all carry fairly high iron, low alkali, and low phosphorus (<3.0% P_2O_5).

Glass slags and vitrified plant products tend to be high in alkali, but the lime content of most wood ashes exceeds 40%, whereas that in glass is much lower. The ratio of potassium/sodium is usually much greater than 1 in wood ash, while it is much less than 1 in seaweed ash. We have not yet been able to obtain an analysis of the vitrified hay-stack in the Natural History Museum, but from its colour, this carries a fairly high iron content derived from the soil. This can happen also when wood is burnt in a pit in such a way that the ash fluxes the soil (Table I, E).

Table I. Composition of Vitrified materials (%)

	A	B	C	D	E
	Cow Dung[1]				
	Kudatini India	England	Vitrified Wood Ash Newcastle	Hawk's Hill Specimen	Ash from Roman Hearth at Gt. Weldon Northants.
SiO_2	67.4	56.3	4.5	> 80	61.0
Fe_2O_3	9.5 (Fe₂O₃ + Al₂O₃ + Mn₂O₃)	17.6 (Fe₂O₃ + Al₂O₃ + Mn₂O₃)	v. little	v. little	17.1
Al_2O_3			n.d.	v. little	16.2
Mn_2O_3			n.d.	n.d.	Nil
CaO	4.4	17.6	60	4.2	3.3
MgO	3.0	0.35	0.27	0.55	0.02
K_2O	6.25	1.54	5.6	7.2	1.77* (K_2O + Na_2O)
Na_2O	2.0	1.68	0.93	1.65	
P_2O_5	3.4	2.46	n.d.	5.06	tr.

Notes

Distinguishing figures ringed.

n.d. = not determined.

* much of the alkali has probably been leached out.

* University of Newcastle-upon-Tyne

Results

The analysis of the Hawk's Hill specimen is given in Table I together with some figures for wood ash and cow-dung. From these results, particularly the high SiO_2 and low lime, it is clear that the Hawk's Hill specimen cannot be wood ash and is most likely to be cow-dung ash, but one must remember that cow-dung ash consists essentially of the straw of the fodder together with some phosphate for the animal, and it would be expected that the only way of distinguishing between straw and hay ash on the one hand and dung on the other would by by the phosphorus content. Some analysis of typical ashes and slags are given in Table II.

Table II Composition wt %

	Copper and Iron Smelting Bloomery Slag	Wood Ash (not vitrified)	Ash tree leaf ash	Coal Ash (vitrified	Peat Ash (not vitrified)
SiO_2	10-40	1.5-6.5	5.5	24-53	3-30
FeO	[45-70]	0-7	0.1	8-30	10-20
CaO	0-7.0	[14-60]	49.6	1-12	[24-30]
MgO	0-2.0	1-25	10.6	0-10	1-7
Al_2O_3	0-15.0	0-2	tr	[19-50]	0-5
MnO	0-15.0	0-30	0.1	0-1.0	0-1
K_2O } Na_2O }	0.3-0.7	[10-20]	19.0 / 1.2	1-2	0-1 / 0-2
P_2O_5	0-3.0	4.0-18	7.07*	0-2	0-3
S	—	0-1.5	2.0	0.1-3.0	[5-10]

Notes

Distinguishing figures are ringed.

* P is generally higher in leaf and bark than in wood.

Conclusions

In most cases there should be no trouble distinguishing between most of the vitrified products although the contaminated ashes such as those from the barn hearth at Great Weldon (Table I) may be confusing. The low silica content of wood ashes seems characteristic; the high silica and moderate phosphate content of dung allows these two to be distinguished. The Hawk's Hill specimen is, therefore, most likely vitrified cow-dung ash.

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Isotope studies of ancient lead

By R. H. BRILL and J. M. WAMPLER
(From American Journal of Archaeology, 1967, 71, (1), 63-77)

The relative proportions of the isotopes of lead vary somewhat among ores occurring in different geographical areas. This is due to the different geological ages of the ore deposits and stems from the fact the Pb^{206}, Pb^{207}, Pb^{208}, are formed as end products of the radioactive decay of uranium and thorium.

The authors have found that when the ratio of Pb^{206}/Pb^{207} is plotted against the ratio Pb^{208}/Pb^{207}, three well defined groups are found, which they call English, Spanish, and Laurion respectively. There seems to be also a fourth group which comes between English and Laurion, and which might be called the Italian group. The boundaries are arbitrary and should be considered as only provisional. It may be that other groups will be found when more samples are tested. The lead samples may be taken from glasses, lead pigs or objects, or glazes on pottery. For example, a few flakes of glaze from a 1st cent. A.D. pot from Caerleon were identified with ore believed to have come from Machen a short distance away. This makes it almost certain that the pot was glazed locally and was not an import. It was found that the red opaque glass from Tara in the Dublin museum resembled in its isotope composition the Italian group rather than the English or Welsh group. It is not improbable for it to be an import, although it is just possible that further work on Irish ores will show that it has Irish affinities.

The authors would be glad to have further samples of ores or suitable objects.

Samples of the following types are required to answer specific questions that have arisen during earlier work. However, all samples from well authenticated sources, or samples from objects having some particular historical significance, will be given serious consideration.

Archaeological Objects

1. Samples from any Old World excavations, particularly in Italy, Spain, Portugal, the Middle East, Mesopotamia, and Macedonia.
2. Objects from Etruscan and Egyptian sources.
3. Objects from Asia.
4. Bronze alloys containing lead; i.e., statues, coins, tools, weapons, etc.
5. Coloured glasses such as are found in mosaics or vessels. These are usually the red, yellow, and green opaques.
6. Lead-glazed pottery sherds or faience.
7. Pigments, such as white lead and red lead, from ancient or more recent historical objects.

Ores

Galena ores (or other lead ores) from the following regions:

Italy, Sicily, Spain, Portugal, Macedonia, Central Europe, anywhere in the Middle East or Far East.

They like to have about 300 mg of lead to do their analyses conveniently, but can work with considerably less (a piece of metallic lead measuring 2 × 2 × 3 mm weighs about 140 mg) Wherever possible, it is desirable to have larger samples. If complete fragments weighing a few grams, or measuring a few centimetres, are available, this allows them to remove surface accretions, make duplicate runs, carry out chemical analyses, and have a more accurate feeling for the types of objects represented. (Unused portions of fragments can be returned if necessary.) Samples of glasses, glazes, alloys and other materials must be heavier than 300 mg, since these materials contain other elements besides lead. If a sample is only 5% lead, one should send a proportionally larger amount of the lead-containing material. Actually for important samples they can do with smaller portions if necessary.

In order to study an archaeological site, it is best to supply between 8 and 20 samples from different dates or find spots, with recommendations as to what relationships might be expected between them. From these a suitable selection can be made.

All samples submitted should be described as accurately as possible in terms of archaeological context, date, nature of the parent object and publication data, if any. It is also helpful to have any additional information available as to why the samples are of particular interest. Also, whenever available, photographs of parent objects should accompany the samples.

Samples should be sent to:

R. H. Brill
The Corning Museum of Glass
Corning, New York
14830
U.S.A.

Minutes of the

THIRD ANNUAL GENERAL MEETING

Held at the Iron and Steel Institute, at 2. 30 p.m. on April 20th, 1967

Present: The President, Sir Frederick Scopes (in the chair), L. B. Hunt, H. O'Neill, B. M. Hardman, H. H. Coghlan, R. Doncaster, W. K. V. Gale, E. E. White, H. F. Cleere, R. C. Dyer, D. W. Dawson, J. A. Reynolds, D. M. Grounds, J. A. Ashdown, C. R. Blick, D. W. Crossley, K. C. Barraclough, G. R. Morton, M. M. Hallett and R. F. Tylecote.

Apologies for absence were received from M. F. Dowding, W. I. Pumphrey, N. Bridgewater, S. H. Russell, W. H.Bailey, N. Mutton and W. A. Smith.

1. **Minutes of the last meeting** on the 26th March, 1966 were approved, and signed by the President.

2. **Matters Arising**. The matter of copyright of articles in the Bulletin was brought up, and it was agreed that this should rest with the author and be indicated in the usual way.

3. **Chairman's Report**

The Chairman reminded members that at the previous Annual General Meeting the association with The Iron and Steel Institute had been endorsed and approval given for similar association with The Institute of Metals; this had now been confirmed. The arrangement was working exceedingly well, and Members would already be seeing the advantages of this co-operation by the improvement in the quality of the last two issues of the Bulletin and by the distribution of reprints from the Journal of The Iron and Steel Institute.

During the year an invitation had been received from the Confederation of British Industries to attend an exploratory meeting on the preservation of industrial monuments. At this meeting a steering committee had been formed to recommend a course of action, and the Group was represented on this committee. A suggested pattern of development prepared by the group had been submitted for discussion and accepted after slight modification. A list of charcoal furnaces worthy of preservation had been prepared and was at present being examined by the steering committee. Details of later furnaces and other iron and steelworks were requested, and the committee of the H.M.G. would welcome suggestions and details from Members.

The 1966 Annual Conference had been an unqualified success, and the 1967 venture promised to be equally interesting.

Work was proceeding on the classification of slags, and it was anticipated that a paper on blast furnace slags would be ready for the next issue of the Bulletin. At the same time it was hoped that two sets of typical slags, with analyses and melting temperatures, along with two sets of colour transparencies, would be available on loan through the Joint Library.

At that Annual General Meeting the President, Sir Frederick Scopes, was due to retire from office, and the Chairman put on record the appreciation of all Members for the excellent work he had done to ensure that the Group had reached so high a standard in so short a time. The Group was assured of his support in the future, particularly in those places where much preparatory work was done.

In the course of the discussion of this report, Mr. Cleere agreed that arrangements would be made to house a complete collection of representative slags in the offices of The Iron and Steel Institute. It was agreed that consideration be given to the Lake District as the venue for the 1968 Conference.

4. **Honorary Secretary's Report**. It was reported that the membership now totalled 350. Of these, 250 came through The Iron and Steel Institute, although they might also be members of other affiliated bodies; 19 were members of The Institute of Metals only, and 82 were not members of either of the metallurgical institutes. There were a small number of organisations with whom publications were exchanged. The membership was still growing at a very rapid rate. Two Bulletins had been published in the year under review, the subjects dealt with including the results of copper smelting experiments, Trojan bronzes, Roman iron, and 18th century blast furnaces. The Annual Conference was held in September in Sheffield and reports were given and discussed on lead smelting in the Pennines, the bloomery at Rockley, the forge at Abbeydale, the crucible and cementation processes, and copper working in Israel. All but the last had been reported in the January issue of the Bulletin.

During the year the Group had been concerned with the future of the blast furnace at Duddon Bridge in the Lake District and had submitted a memorandum on the subject. It would seem that there was now every possibility that the site will be well preserved and made available for inspection.

5. Treasurer's Report. The Honorary Treasurer presented his unaudited accounts for inspection. He pointed out that the present arrangements by which the I.S.I. are responsible for the Group's publishing activities had saved a considerable amount of money and were mainly responsible for the healthy state of the balance sheet. There had been an increased income from subscriptions and from sales of back-numbers of the Bulletin. A small profit had been made on the conference. He recommended that the annual subscription should be raised to £1, so that they should pay something towards the additional cost of postage, which was now a very large proportion of the 10/-. The report was accepted and the subscription rates approved. Dr. W. I. Pumphrey was re-elected Honorary Auditor.

6. Election of Officers for the Year 1967-68

Mr. M. F. Dowding was unanimously elected President. The Chairman proposed a vote of thanks to the retiring president, Sir Frederick Scopes, which was seconded by the Honorary Secretary. In view of the new President's absence, Sir Frederick was asked, and kindly agreed, to continue in the chair. He was then presented with a token of the Group's gratitude for all the work that he had done and the risks that he had taken in being the first president of a new organisation.

As there were no other nominations for the posts of officers or for the committee, the following were declared elected:

Chairman:	G. R. Morton.
Hon. Secretary:	R. F. Tylecote.
Hon. Treasurer:	M. M. Hallett.
Committee:	K. Barraclough.
	C. R. Blick.
	N. Bridgewater.
	D. Crossley.
	M. W. Flinn.
	B. M. Hardman.
	W. K. V. Gale, H. F. Cleere } representing The Iron and Steel Institute
	Prof. H. O'Neill, representing The Institute of Metals.

7. Third Annual Conference

It was announced that this would take place in the Forest of Dean on the week end of 22nd-24th September. The subject would be the Industrial History of the Forest of Dean. It was being organised by two Members, Dr. Cyril Hart and Mr. Norman Bridgewater. Talks on various aspects of metallurgy and industry in the Forest would be supplemented with visits to sites of metallurgical interest. It was agreed at the meeting that wives and non-members would be welcome.

8. Publications and Future Work

Mr. Cleere spoke on the subject of the Bulletin and asked members to provide news and abstracts of articles of historical interest. It was agreed that there might be a page of half-tone plates in the Bulletin to supplement the line drawings, which reproduced very well.

Mr. Gale pointed out that the steelworks of Bairds were being dismantled and it might provide interesting material. It was also pointed out that Gjers, Mills had been demolished and that the Kidwelly tin-plate works was going. Mr. Barraclough also pointed out that the acid open hearth process was rapidly becoming obsolete.

The Chairman emphasised the work being done by the economic historians and that much effort was being given to this aspect in Colleges of Technology where it acted as a useful addition to purely technical subjects.

9. Affiliation to the Council for British Archaeology

It was agreed to accept Mr. Cleere's proposal that affiliation should be sought with the C.B.A. It was suggested that discussions should be sought with the C.B.A. It was suggested that discussions should be opened on a possible relationship with the Industrial Archaeology Sub-Committee of the C.B.A. with a view to having representation on it.

10. Next Meeting

It was agreed that the next Annual General Meeting should be held at the offices of The Iron and Steel Institute.

11. Other Business

Mr. Ashdown mentioned that the Post-Medieval Archaeology Research Group obtained funds from the Ministry of Public Buildings and Works, some of which might be available to the H.M.G.

The formation of a Weald Research Committee was announced (see News). This would consist of a group of local correspondents which would act as a clearing house for suitable material. Attention was drawn to the fact that a good deal of material gathered by Straker was still unpublished.

It was also noted that the aluminium works at Foyers, near Inverness was being dismantled and that it had records and equipment of interest. This was in good hands.

Mr. Cleere mentioned that The Iron and Steel Institute was willing to house archives, although those relating to ferrous metallurgy would be preferred. He also mentioned that the International Union of Prehistoric and Protohistoric Sciences had set up an Iron Committee on which he and the Honorary Secretary had accepted invitations to serve.

It was noted that the 7th Commonwealth Conference of Mining and Metallurgy would be held in Britain in 1969 and that some historical tours were being arranged in connection with it. Mr. Gale and Mr. Cleere were on the responsible committee.

Sir Frederick Scopes noted that only 5% of the members participated in the activities of the Group and called for wider participation in order to make the work more effective.

On behalf of all Members, Mr. Blick thanked Sir Frederick for taking the chair and for his work for the group, and also thanked The Iron and Steel Institute, and in particular Mr. Cleere, for the help that they had given, and for allowing the use of the Council Room for the meeting.

Notes and News

WEALDEN IRON RESEARCH COMMITTEE

Mr H. F. Cleere and Mr D. W. Crossley are taking the initiative in forming a Wealden Iron Research Committee. The object of the Committee will be to reasses the sites listed in E. Straker's 'Wealden Iron', published in 1931, and to bring together new information on Wealden sites, with the ultimate intention of publishing an up-to-date gazetteer of sites, combined with a history of the industry from prehistoric times until its end in the seventeenth century.

The Historical Metallurgy Group and The Iron and Steel Institute are supporting the venture, which also has the approval of the Sussex Archaeological Society and the Council for British Archaeology. Members wishing to know more about the Committee and to collaborate in its work are invited to contact Mr Cleere at The Iron and Steel Institute, 4 Grosvenor Gardens, London S.W.1, or Mr Crossley at the University of Sheffield, Department of Economic History, Sheffield 10.

EXCAVATIONS 1967

Orznash Mr. J. H. Money is completing his excavations at the Roman and medieval bloomery site at Minepit Wood, Withyham, Sussex, this year.

Charlcote Excavation and restoration of the Charlcote blast furnace will continue throughout the year under the direction of the Chairman of the Group (Mr G. R. Morton).

Muncaster Head The Honorary Secretary (Dr R. F. Tylecote) will be exacavating the bloomery site at Muncaster Head, Cumberland, during July 1967.

Panningridge Mr D. W. Crossley will be continuing his excavation at the 16th century Panningridge furnace, near Robertsbridge, Sussex, in the second half of August.

Bardown After an interval of nearly two years, the excavation of the Bardown Roman bloomery site near Wadhurst, Sussex, will be resumed this year during the first three weeks of August under the direction of Mr. H. F. Cleere. It is hoped that weekend digging will continue during the autumn.

NUMBERING OF THE BULLETIN

Members will observe that the cover of this issue of the Bulletin bears the legend 'Vol. 1-No. 9'. It is proposed to complete Volume 1 with this issue, and in future to group two successive issues of the Bulletin in each volume. Thus Volume 2 will consist of the two issues published during 1968. Individual issues will continue to be published in January/February and July/August each year and will be numbered Part I and II. Page numbering will be consecutive throughout each volume.

Abstracts

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

Members are invited to prepare abstracts of papers of interest that they read and send them for inclusion in the Bulletin, to H. F. Cleere at The Iron and Steel Institute, 4 Grosvenor Gardens, London S.W.1.

BRITISH ISLES

The iron and steel industry in Great Britain from the 18th cent. to 1914 Y. Fabian (ISEA Sidérurgie et croissance economique en France te en Grande-Bretagne 1735-1913, 1965, Feb., **T**. 5,(158), 153-200; bibl.:245-261) [In Fr.] Technological changes and the growth of the industry are outlined. Tables for areas give blast furnaces and iron and steel production.

The management of a 16th cent. iron works D. W. Crossley (Econ. Hist. Rev., 1966, **19**, Aug., (2), 273-88) A study of profitability, availability of supplies, and managerial techniques based on an examination of ironworking accounts for the furnaces and forges around Robertsbridge (Sussex) controlled by Sir William Sidney and later by his son, Sir Henry, between 1541 and 1576. A building notebook for another furnace nearby at Panningridge has also been studied.

Little Aston Forge: 1574-1798 G. R. Morton and J. Gould (JISI, 1967, **205**, March, 237-244) This paper traces the history of the Little Aston Forge from 1574 through the era of the charcoal-using Foleys, and gives special emphasis to the period of occupation by John Wood. The Wood family, from the time of William 'Coiner' Wood, had been interested in the use of raw coal in the production of malleable wrought iron, and it was under the ownership of John Wood that considerable success was achieved at his works at Wednesbury and Little Aston. Whereas no remains exist at Wednesbury, sufficient are available at Little Aston to give a clearer understanding of the processes involved, and the writers consider these facts from both historical and technical points of view.

Some details of an early blast furnace G. R. Morton (Iron Steel, 1966, **39**, Dec., 563-566) A description of the remains of the Cannock Chase works and a probable reconstruction of the furnace and its working.

Swindon, the last of the old hand mills (Ingot News, 1966, July, p. 6; Man Met., 1966, **43**, (9), 264-5) A brief histocal outline of the works (said to have begun in the 16th cent.) to mark the closing of the hand mill section at RTB Ltd's Swindon Works on the Snetstow, Staffs. Thomas Ffolley carried out rolling and tinplating there from 1668; he was aided by his relationship with the Hanburys, and followed his father Richard, who is believed to have first introduced rolling and slitting machines in England, c. 1630, at his nearby works, The Hydes, on the Stour.

Searching backward for refractories—the Wealden Black Country D. Dixon and L. C. Dixon (Refract. J., 1967, **43**, Jan., 20-22) The history of the Wealden glass industry can be traced to the work of French immigrants in the 13th century, while the iron industry in this area is even older. Local ironstone and sand with charcoal fuel appear to have been the main raw materials.

EUROPE

The Siegerland lift-hammer: An example found in Boschgotthardshütte of 1467 F. Oehler (Stahl Eisen, 1967, **87**, 23 Feb., 107-209) [In Ger.] A special type of water-powered hammer is described which was used in the Siegerland 500 years ago. A model of this hammer is exhibited in the museum of the Siegerland.

75 years of steel from Hamborn (Unsere ATH, 1966, **12**, Dec., 3-43) [In Ger.] A collection of articles illustrated by photographs of works and company archives to mark the founding of the Hütte Bruckhausen in 1891 and its development into the present August Thyssen-Hütte AG, Duisburg-Hamborn. Outlines are given of the social and economic activities of the Thyssens and the growth of the company.

Study of the history of the iron industry and of the common market in coal and steel of the Mosellan basin J.-P. Koltz (Rev. Techn. Luxembourg, 1966, July-Sept., 105-117) [In Fr.] A general historical review of the industry in this region. (35 refs.)

Classification of ancient slags found in Poland and the statistical analysis of their chemical composition J. Piaskowski (Kwart. Hist. Kult. Mat., 1966, **4**, (2), 335-356, reprint) [In Pol.] Ironmaking slags (II to XIIIth centuries) have been analysed. The results are shown in diagrams and tables.

ASIA

Iron making in ancient China Lu Ta (Acta Met. Sin., 1966, **9**, (1), 1-3) [In Chinese] Metallographic studies of antique iron utensils that have unearthed in various parts of China revealed the structures of white cast iron, hammered low-carbon steel, and blackheart malleable iron, from the 3rd or 4th Centures BC. Brief descriptions are given of a crucible furnace for iron smelting, of the possible ways of converting white cast iron into malleable metal, and of ancient methods of making swords.

Tatara... An introduction to the traditional steelmaking process of Japan J. Kozuka (Tetsu-to-Hagane, 1966, 52, Nov., 1763-1778) [In Jap.]

METALLURGICAL INVESTIGATIONS

Metallographic study of two Frankish swords of the 9th century H. E. Bühler and C. Strassburger (Arch. Eisenh., 1966, **37**, Aug., 613-619) [In Ger.] One of the swords was manufactured from one piece, case-hardened, and quenched. The carbon level was on the average 0.79%. The other was of the Damascene type and consisted of nine layers which were forge-welded. The layers were alternating P-rich and low-P (0.7 and <0.1%P). (21 refs.)

The manufacturing technique of Etruscan weapons. Examination of an iron spear-head (IV century B.C.) from Montefiascone C. Panseri and M. Leoni (Met. Ital., 1966, **58**, Oct., 381-389) [In Ital.] A series of metallographic examinations of an Etruscan spearhead of the 4th century B.C. has shown that the specimen had been obtained by the Damascene technique. Two of the laminations were ascertained by electron-beam examination to be of meteoric iron, and their symmetrical position relative to the core showed that they had been deliberately introduced. The sacred character attributed to meteoric iron and the place where the spear-head was found (the Sanctuary of Fanum Voltumnae Montefiascone) favour the supposition that it may have been a votive weapon.

Metallographic examinations of iron objects from the early medieval settlement at Czeladz Wielka (Góra, Poland) J. Piaskowski (Silesia Antiqua, **8**, 150-175, reprint) [In Pol.] Analytical and metallographic observations are given for 18 objects dating between the 6th and 12th cents.

Further metallographic examinations of Hallstatt period iron objects found in Poland and Silesia J. Piaskowski (Fontes Archaeol. Posnan., 1962, **13**, 217-245, reprint) [In Pol.] A study of 14 objects.

Further investigation on the technology of Halstatt and early La Tène period iron objects found in Poland J. Piaskowski (Kwart. Hist. Kult. Mat. 1963, **11**, (1), 3-28, reprint) [In Pol.] A study of 215 objects.

Ancient damascene steel in the light of present-day metallurgy J. Piaskowski (Kwart. Hist. Nauki i Techn., 1965, **11**, (3), 241-7, reprint) [In Pol.] A review and evaluation of theories. Carbon content, heat treatment, reforging, and acid etching are held to be the critical factors.

Metallographic investigations of ancient iron objects in Poland and their application in archaeology J. Piaskowski (Archeologia Polski, 1965, **10**, (2), 723-750, reprint) [In Pol.] A review of work and theories since 1953.

Metallographic examinations of iron objects from the cremation cemetery at Zadowice, Kalisz J. Piaskowski (Prace Mat. Mus. Archeol. Ethogr. Lodz, 1966, (13), 213-230, reprint) [In Pol.] An examination is reported of nine objects (3-4 cent. AD) which are presumed to have come from the Swietokrzyskie mountain area.

PROCESSES

History of iron and steel processes W. S. Atkins (J. Jun. Inst. Eng., 1966, **76**, Feb./March, 151-177) A non-technical history of the development of the blast furnace and the production of steel.

BIOGRAPHY

Great steelmakers of the last 100 years M. Schofield (Steel Times, Ann. Rev. Centenary No., 1966, Oct., 105-111) An account of the work of Bessemer, Siemens, Martin, Thomas, Mushet, and others in founding the modern steel industry.

MISCELLANEOUS

Le Musée de l'Histoire du Fer, Nancy H. F. Cleere (JISI, 1967, **205**, Jan., 15-16) A short description of the new Museum of the History of Iron.

Industrial archaeology and the church M. M. Rix (Indust. Archaeol., 1967, **4**, Feb., 44-50) Brief accounts are given of cast-iron grave slabs in the Weald and the Shropshire-Herefordshire region. An outline is also given of the use of cast iron in English church architecture, monuments, and fittings from 1770's.

Folk-art under-foot G. J. Smith (Found. Trade J., 1966, **121**, 15 Dec., 790-791) A brief description (with 16 illustrations) of the history and variety of cast-iron coal-hole plate covers. Rubbings of the patterns on these plates ('opercula'), representing a popular art-form, are sought by collectors.