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Contents

The metallography and chemical analysis of iron-base samples dating from antiquity to modern times

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INTRODUCTION

Dr Nikolaas J. van der Merwe is an Associate Professor of Anthropology at the State University of New York at Binghamton. His doctoral thesis for Yale University was entitled 'The Metallurgical History and Carbon-14 Dating of Iron'. Dr van der Merwe, in order to develop the method for carbon-14 dating of manufactured iron, received iron specimens of known archaeological age from many museums and private donors. Thus, he was able to compare the carbon-14 age of the iron specimens against the historical age.

The method of carbon-14 dating depends upon the extraction of carbon from the alloy in the form of CO_2 by means of direct combustion. The carbon-14 activity of the CO_2 is then determined to provide an age. The method assumes that the carbon content of the alloy is derived from the fuel used to smelt the ore—a safe and reasonable assumption. There are two conditions restricting the use of the method. If the iron specimen has a low carbon content, a large amount of sample must be available to provide a sufficient amount of CO_2 for an accurate age determination. If the source of the carbon in the alloy is coal or coke, a carbon-14 activity will not exist. The latter does not really restrict the use of the method because before the 18th century iron ores were smelted primarily by the use of charcoal. Hence, if a carbon-14 activity is not registered, the iron specimen can reasonably be assigned a maximum age.

The opportunity to do the metallography of these very interesting metal specimens became available through Mr Uno T. Hill of Inland's Chemical Department. He and Dr van der Merwe have a mutual friend who suggested the collaboration. The photomicrographs were prepared by the author in the Metallurgical Laboratory of the Technical Service Department, Inland Steel Company.*

METALLOGRAPHIC PRACTICES

The metallographic techniques were routine and standard practices of the Laboratory. Some of the samples required special care in sectioning because of their awkward or limited size. The specimens were mounted for polishing in Buehler's AB Moulding Powder and Bakelite Powder. The microspecimens were polished through 600 grit abrasive paper, followed by lapping on a silk cloth impregnated with Elgin diamond compound, grade No. 6, and were finally polished on a felt cloth with Linde 0.3 A micron alumina. In some cases, the samples were finally polished on a mechanical lapping device using Linde 0.3A alumina. The following etching reagents were employed:

3% Nital: 1800 ml denatured ethyl alcohol; 75 ml C.P. nitric acid

Picral: 400 ml ethyl alcohol; 23.6 g picric acid

Alkaline Sodium Picrate: 500 ml distilled water; 10 g picric acid; 125 g sodium hydroxide

The identification of the microconstituents did not present any great difficulty. The primary phases were identified through knowledge of their morphology and etching characteristics. A micro-hardness indentor was also useful for identifying the phases. The identification of non-metallic inclusions was based upon their optical characteristics under reflected white light and reflected plane polarized light with crossed Nicol filters. The oxy-sulphide classification includes the iron-manganese sulphide and iron-manganese oxide types. The complex classification refers to silicate-aluminate types. At any rate, the identity of inclusions is neither specific nor, in some cases, precise.

THE RESULTS

The results are summarized in two tables; Table I lists the cast irons and Table II the wrought irons and steels.

Cast Irons

The three Chinese irons are all white. N3 is from the feudal state of Han, near Loyang, Honan province, and is dated to the 5th to 3rd century BC. C14 dating confirms this date (430 ± 80 BC). It is a hypereutectic iron showing primary cementite platelets in a eutectic matrix (Fig. 1a and b); both the eutectic and the eutectoid are degenerated and thus the structure consists of ferrite in a cementite matrix. N23 is a fragment from the grating of a stove from Sian and the dating is 2nd century AD which is confirmed by C14 dating. The structure is that of a hypoeutectic iron containing graphitic nodules, each of which was surrounded by a primary austenite which had transformed to pearlite (Fig. 2a and b). The matrix was the austenite-cementite eutectic, ledeburite, and of course the austenite of the ledeburite had transformed to pearlite. N24 was from the cast-iron statuette of a cow dated to 4th-10th century AD, from Hunan province, China. The C14 dating gave 1550 ± 60 AD. The structure was that of a hypoeutectic iron showing an aggregate of primary austenite and ledeburite in a matrix of cementite. The austenite transformed to pearlite at 720°C. The identification of the white-etching cementite matrix was confirmed by microhardness and alkaline sodium picrate. Sparse small graphite flakes were also present.

N1 is a cast iron from a coke-smelted pot-bellied stove and shows graphite flakes with rosette groupings and steadite in a pearlite matrix. N4 is a part of a crane hook from Saugus Ironworks. It has a mid-17th century date which was confirmed by C14 dating. It consisted of graphite flakes and steadite in a pearlitic matrix. N13 is an iron fragment from the John Winthrop Jr. Ironworks at Quincey, Mass., and is dated 1644-1647. It showed uniform and random graphite flakes with steadite in a pearlitic matrix. N14 was part of a stove from Fort Kiowa, Lyman Co., S. Dakota. C14 dating indicated coke-smelted iron. Its structure was graphitic with random flakes and rosette groupings. Ferrite was associated with the rosettes. Steadite was present and the matrix was pearlitic.

N15 comes from an axle thimble of a buckboard from Fort Lower Brule, Lyman Co., S. Dakota, which was established in 1877-78. It consists of graphite flakes in ferrite. There is a network of fine pearlite separating rosette groupings with steadite in the pearlite (Fig. 3). N16 is from a waggon thimble from Fort Berthold, McLean Co., N. Dakota. Its age was given as 1845-85 and C14 dating indicated 'coke-smelted iron apparently reworked in a charcoal furnace by a blacksmith'. Again it consisted of a graphitic iron with ferrite in rosette groupings and adjacent to some of the randomly distributed flakes with steadite and a pearlitic matrix. N17 came from the debris of Hopewell furnace, which worked between 1772 and 1845, and the C14 date confirmed this (1750 ± 60). The structure showed uniformly distributed graphite flakes with steadite in a coarse pearlitic matrix. N22 was a stove plate from Redding furnace, Pennsylvania;

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* Only a few have been reproduced here; the full collection has been deposited in the H.M.G. library at The Iron and Steel Institute (Ed.)

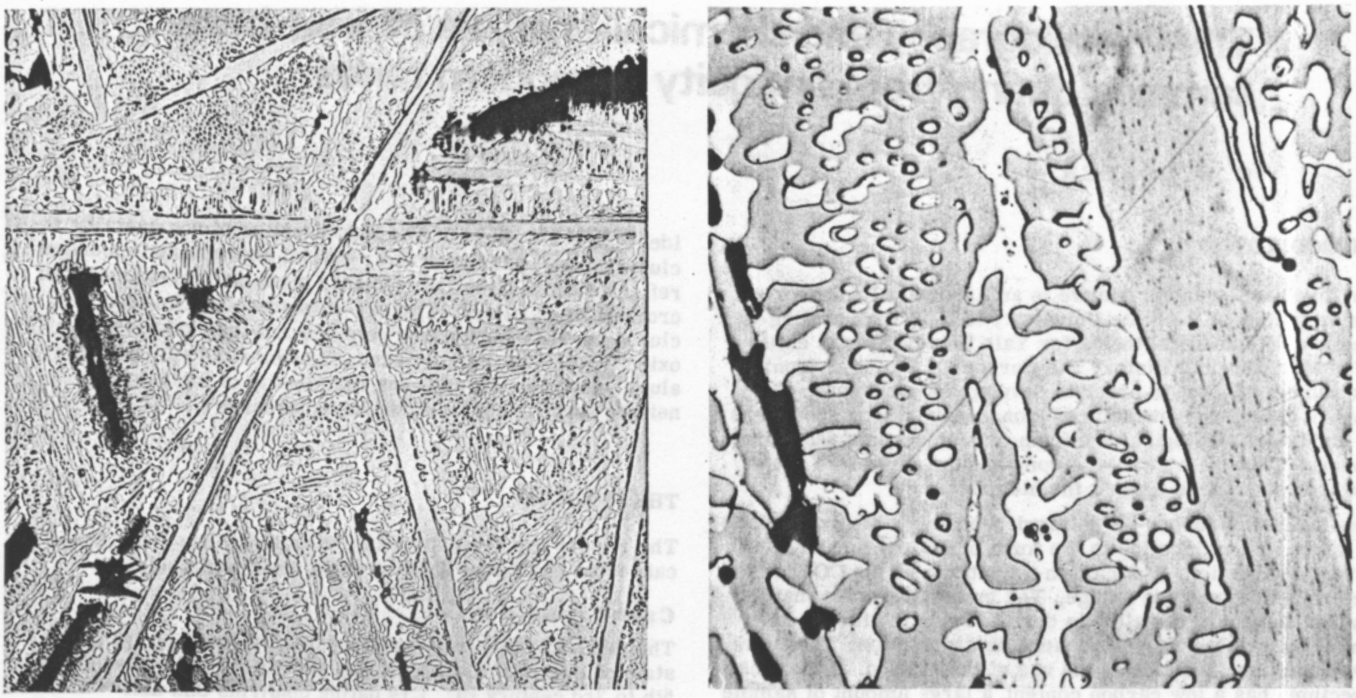

Fig. 1 — Sample N3: cast iron from the feudal state of Han, near Loyang, Honan Province. Age: 5th to 3rd century BC. Carbon-14 date: 430 ± 80 BC.

Microstructure (a × 100, b × 500): Hypereutectic cast iron showing primary cementite platelets in a eutectic matrix the austenite transforms to pearlite at 813°C); both the eutectic and eutectoid are degenerated, hence the microstructure consists of ferrite in a cementite matrix.

Chemical composition, %

Total C	Mn	P	S	Si	Cu	Ni	Cr
4.19	0.11	0.80	0.014	0.055	0.018	0.029	0.006

TABLE I Cast irons: compositions and structures

Sample No.	N1	N3	N4	N13	N14
Object	Pot-bellied Stove	Chinese casting (Loyang)	Crane hook (Saugus)	Iron frag. (Winthrop, Mass.)	Stove, Fort Kiowa, S. Dak.
Arch. date	Recent	Han(5th-3rd B.C.)	Mid 17th A.D.	1644-47	?
C 14 date	Coke	430 ± 80 BC	1600 ± 60	Coke	Coke
C(total)	3.64	4.19	3.70	3.59	3.47
Mn	0.51	0.011	1.15	0.51	0.66
P	0.27	0.080	0.72	0.85	0.72
S	0.10	0.014	0.05	0.04	0.18
Si	1.61	0.055	0.74	1.75	1.77
Cu	—	0.018	—	—	—
Ni	—	0.029	—	—	—
Cr	—	0.006	—	—	—
Type	Grey	White	Grey	Grey	Grey

TABLE I Cast irons: compositions and structures continued

Sample No.	N16	N17	N22	N23	N24	N27
Object	Waggon thimble (Fort Berthold, N.D.	Casting (Hopewell Furnace).	Stove-plate (Redding, Penn.)	Stove (Sian, China)	Statue of cow (Hunan)	Cannon ball (Bermuda)
Arch. date	1845-85	1772-1845	1761	Han(3rd BC -2nd AD)	4-10th AD	1838
C 14 date	Coke	1750 ± 60	1770 ± 60	110 ± 80 BC	1550 ± 60 AD	—
C(total)	3.22	4.07	3.99	4.32	2.97	3.52
Mn	0.47	0.11	0.12	0.07	0.09	0.16
P	0.72	0.147	0.067	0.38	0.29	1.13
S	0.15	0.016	0.016	0.027	0.067	0.061
Si	0.072	0.68	0.37	0.11	0.06	0.079
Cu	—	0.33	0.13	0.029	0.11	—
Ni	—	0.02	0.01	0.01	0.01	—
Cr	—	Mo 0.004	Mo 0.004	Mo 0.004	Mo 0.008	—
Type	Grey	Grey	Grey	White	White	Grey

TABLE II Wrought irons and steels: compositions and structures

Sample No.	N2	N5	N6	N7	N8	N9	N10	N11	N12
Object and Provenance	Nails (Inchtuthil, Perthshire	Italian Armour	German Armour	Italian Armour	Italian Sword	Italian Armour	Merovingian sword (S. France)	German Armour	Iron tie (Ipswich, Mass.)
Arch. date	AD 83-87	1400	1550	Late 15th C	Early 16th C	1480	8th C AD	16th C	Late 17th -early 18th C.
C 14 date	AD 100 ± 80	—	—						
Analysis, %									
C	0.17	0.10	0.16	0.47	0.10	0.23	0.17	0.62	0.10
Mn	0.07	0.002	0.05	0.06	0.02	0.011	0.09	0.08	0.005
P	0.10	0.025	0.02	0.003	0.246	0.003	—	0.004	0.025
S	0.008	0.021	0.009	0.004	0.025	0.004	—	0.004	0.004
Si	0.03	0.14	0.060	—	0.123	0.067	—	0.04	0.028
Cu	0.015	0.009	0.004	0.009	—	0.009	—	nil	—
Ni	0.01	nil	0.016	nil	—	nil	—	nil	—
Mo	0.008	—	—	—	—	—	—	—	—
Cr	—	0.026	0.008	0.008	—	nil	—	0.008	—

Sample No.	N18	N19		N20	N21	N28	N29	N30		
Object and provenance	Iron (Fort Atkinson)	Hoe or adze (Trichardt, Trans-vaal, S. Africa)		Fragment (Denbigh, Va.)	Fragment (Williams-burg, Va.)	Bolt from wreck of 'Virginia Merchant'	Piece from Frobisher Sound	Nails from Washington's Chest		
Arch. date	1820-1827	Iron Age		Before 1650	1816-17	Before 1660	1587	1776-1885		
								A	B	C
C 14 date	—	—		—	—	—	—	—	1776	1885
Analysis, %										
C	0.09	0.39	0.27	0.63	0.09	0.07	0.16	0.05	0.26	0.01
Mn	0.002	0.002	0.001	0.01	0.005	0.08	0.08	nil	nil	nil
P	0.164	0.077	0.046	0.012	0.27	0.024	0.16	0.015	0.115	0.055
S	0.016	0.007	0.004	0.004	0.005	0.007	0.041	—	0.036	0.016
Si	0.014	0.038	0.047	0.06	0.076	0.07	0.02	0.003	0.18	0.41
Cu	—	—	—	—	—	—	—	—	—	—
Ni	—	—	—	—	—	—	0.002	—	—	—

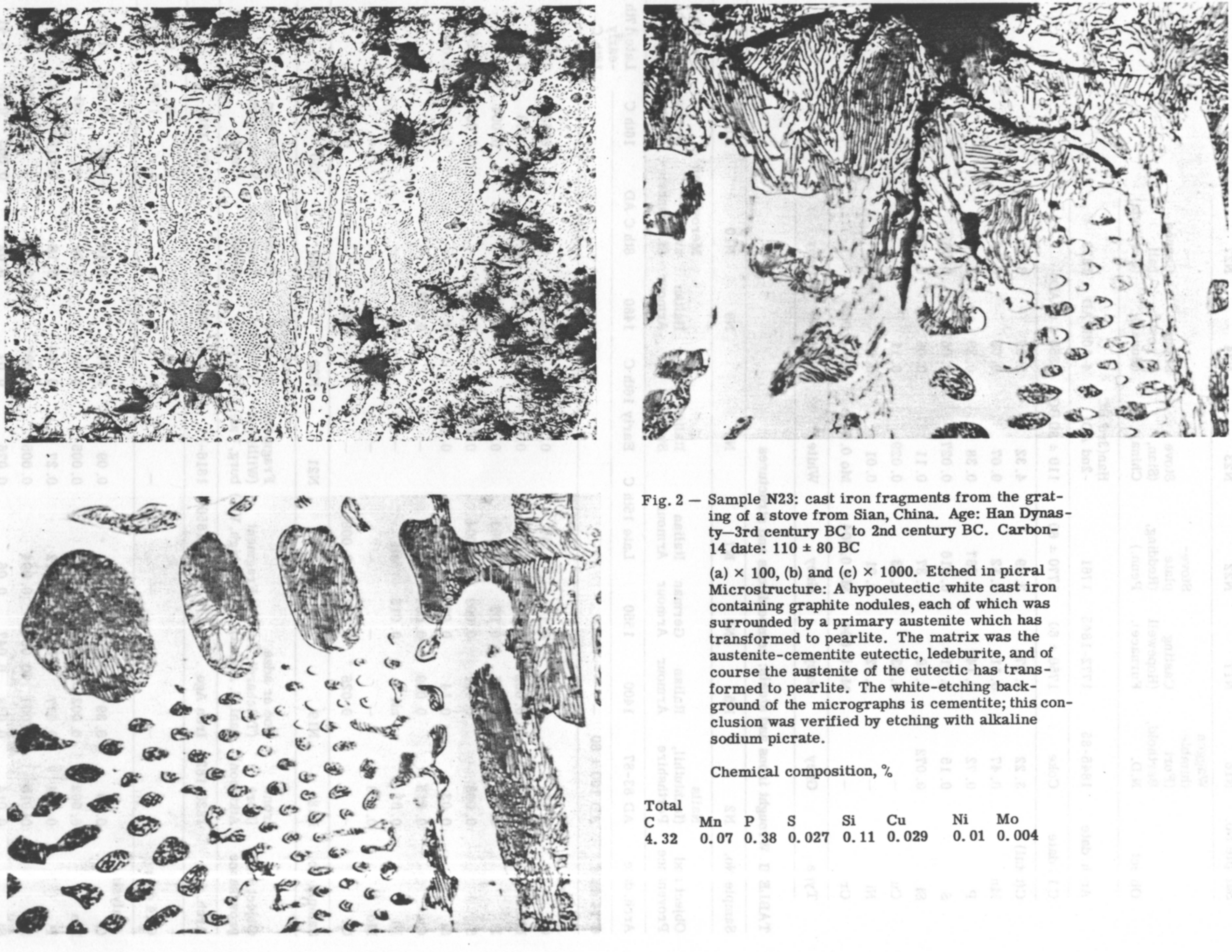

Fig. 2 — Sample N23: cast iron fragments from the grating of a stove from Sian, China. Age: Han Dynasty—3rd century BC to 2nd century BC. Carbon-14 date: 110 ± 80 BC

(a) × 100, (b) and (c) × 1000. Etched in picral Microstructure: A hypoeutectic white cast iron containing graphite nodules, each of which was surrounded by a primary austenite which has transformed to pearlite. The matrix was the austenite-cementite eutectic, ledeburite, and of course the austenite of the eutectic has transformed to pearlite. The white-etching background of the micrographs is cementite; this conclusion was verified by etching with alkaline sodium picrate.

Chemical composition, %

Total C	Mn	P	S	Si	Cu	Ni	Mo
4. 32	0. 07	0. 38	0. 027	0. 11	0. 029	0. 01	0. 004

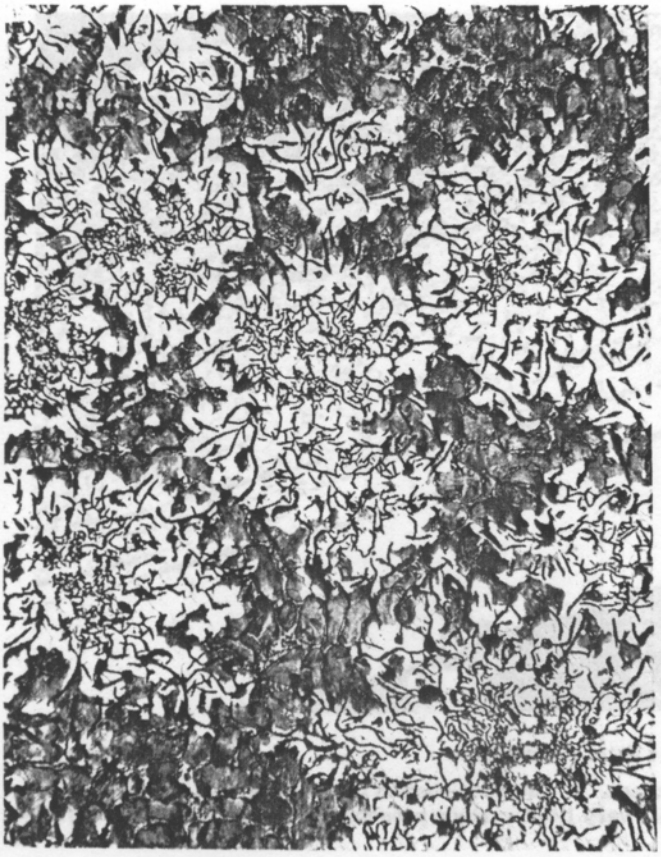

Fig. 3 — Sample N15: Fragment from the axle thimble of a buckboard from Fort Lower Brule, Lyman County, South Dakota. Age: Fort established 1877-78. Carbon-14 date: Unavailable.

Microstructure: Cast iron, graphite flakes in ferrite. Network of fine pearlite separating rosette groupings. Steadite network in pearlitic areas. Magnification × 300, etched in picral.

Chemical composition, %

Total C	Mn	P	S	Si
3.38	0.67	0.70	0.10	0.062

its age was given as 1761 which was confirmed by C14 dating (1770 ± 60). It showed graphite flakes both with random and rosette groupings with steadite and a pearlitic matrix.

N27 was a small cannon ball from the wreck of a French frigate, L'Herminie, lost off Bermuda on December 2nd, 1838. It was a grey cast iron with random graphitic flakes with steadite in a coarse pearlitic matrix.

Wrought Irons and Steels

The earliest material examined were the Roman nails from the Roman legionary fort at Inchtuthil, Perthshire. They were deposited between AD 83 and 87 and this date was confirmed by C14 dating (AD 100 ± 80). Two nails were examined by longitudinal sections. The first nail had coarse and fine ferritic grains as well as slag stringers at the surface and just below it. Another area showed fine ferrite (ASTM grain size 7-8) and dark-etching pearlite nodules. Nail 2 had uniform ferrite grains and discrete inclusions, probably of iron oxide, and there was some grain-boundary pearlite in the low-carbon areas. In the high-carbon areas there were ferrite-rimmed pearlite colonies.

A number of specimens of body armour were examined. N5 was Italian of AD 1400. It consisted of wrought iron with a lightly carburized surface (Fig. 4). The top surface showed ferrite, pearlite, and grain-boundary cementite. The bottom surface was ferrite with very little carbide. The inclusions were primarily oxy-sulphide types. N7 showed late 15th century armour with pro-eutectoid ferrite and pearlite. A second piece gave ferrite and partially spheroidized pearlite; this piece was probably reheated. Both pieces appeared to be steels rather than carburized wrought iron. The inclusions were mainly complex. N9 was another piece of Italian armour dated to AD 1480. A full cross-section showed highly carburized wrought iron which had been quenched following carburization. The ferritic core showed angular fine pearlite. The carburized zone showed bainite, troostite, fine pearlite, and ferrite.

N6 and N11 were specimens of German armour. N6 is dated to AD 1500 and consisted of wrought iron with a carburized surface. The carburized surface consisted of ferrite, pearlite, and spheroidized pearlite; the rest was ferrite and small angular grain-boundary cementite (very sparse). The inclusions were primarily oxy-sulphides. N11 was also dated to the 16th century. It was a high-carbon steel with a decarburized surface; it consisted of ferrite and pearlite.

N8 was an Italian sword of the early 16th century. A transverse section showed that one surface was highly carburized with a wrought-iron core showing very little carbide (Fig. 5). The opposite surface had deteriorated but showed evidence of carburization. The carburized zone showed upper bainite, troostite, and fine pearlite, indicating a quench after carburizing. N10 was a Merovingian sword blade from southern France and dated to the 8th century AD. It had a non-uniform carbide distribution resulting in a ferrite-pearlite microstructure, and ferrite with grain-boundary cementite. The ferrite grain size was ASTM 9-10 in some places and 8 in others. The structure was more indicative of a steel rather than a wrought iron. The inclusions were mainly complex.

N12 was a cylindrical piece of an iron tie from a house in Ipswich, Mass. Its age was late 17th to early 18th century. The structure was one of ferrite and pearlite with a transition into a quenched structure of untempered martensite and troostite. The quenched zone was irregular in configuration, encompassing about one-third of the circumference and penetrating to the centre of the round. N18 was an iron sample from Fort Atkinson, which was occupied from 1820-1827. It was not homogeneous, one corner being high-carbon with pearlite colonies outlined by ferrite and the rest being low-carbon iron showing coarse-grained ferrite and oxy-sulphide inclusions.

N19 represented two pieces of metal from an iron hoe or adze picked up 8.6 miles from Bauis Trichardt along the Trichardt-Messina road, in South Africa. Its date is that of the Transvaal Iron Age. The full cross-section starting from the surface of one piece showed mixed ferrite and pearlite with fine grain, an open oxide-filled seam, coarse ferrite grains and inclusions, then a transition to a very fine-grain ferrite and pearlite-ferrite zone approaching the other high-carbon surface. The seam probably represents the joining of two different pieces of metal. The second piece showed sheets of metal which were folded over upon themselves and laminated with other sheets. The microstructure of the folded-over and laminated area (Fig. 6) consisted of ferrite, pearlite, partially spheroidized pearlite, and cementite. Etching with alkaline sodium picrate indicated that the bands were ferritic; however, some of the bands had a very fine dispersal of cementite. An etch with Stead's reagent indicated a high-phosphorus segregation within the bands.

N20 was a fragment from a refuse site at Denbigh Plantation, Warwick County, Va. Its terminal date was in the second quarter of the 17th century. It consisted of a spheroidal cementite and partially spheroidized pearlite in a ferrite matrix, with complex inclusions. In some areas the cementite was completely spheroidized. The sample also showed areas of very heavy oxy-sulphide inclusions with very little carbide.

N21 was a fragment from a shop cellar on the site of the new U.S. Post Office in Williamsburg, Va. It was found in association with coins of 1816-17. It consisted of very large grains. of ferrite with some grain-boundary cementite. The surfaces were carburized and the cementite in the very coarse pearlite was spheroidizing and coalescing. A short rod-like

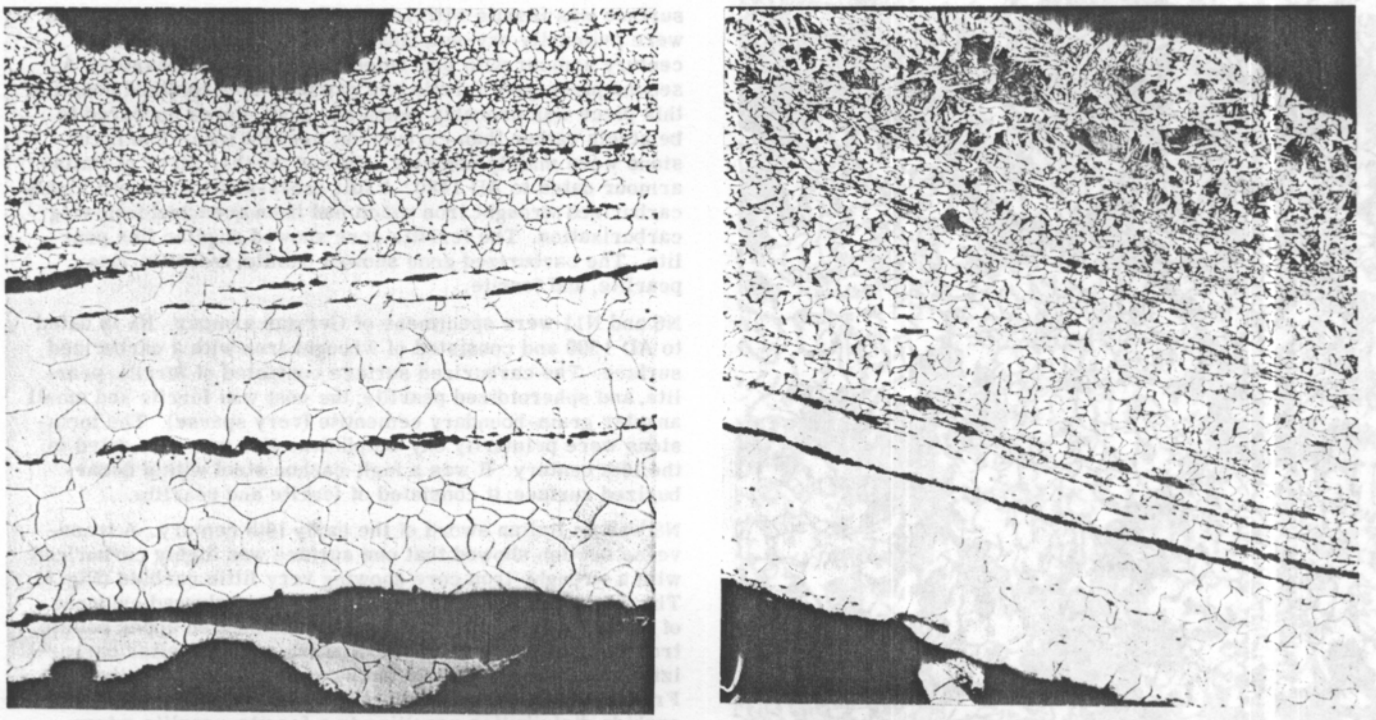

Fig. 4 — Sample N5: Italian armour plate. Age: AD 1400. Carbon-14 date: Unavailable.

Microstructure: A wrought iron with lightly carburized surface. Top surface showed ferrite, pearlite, and grain-boundary cementite microstructure. Bottom surface ferrite with very little carbide present. Inclusions primarily oxysulphide type. Magnification × 100, etched in nital.

Chemical composition, %

C	Mn	P	S	Si	Cu	Ni	Cr
0.10	0.002	0.025	0.021	0.140	0.009	nil	0.026

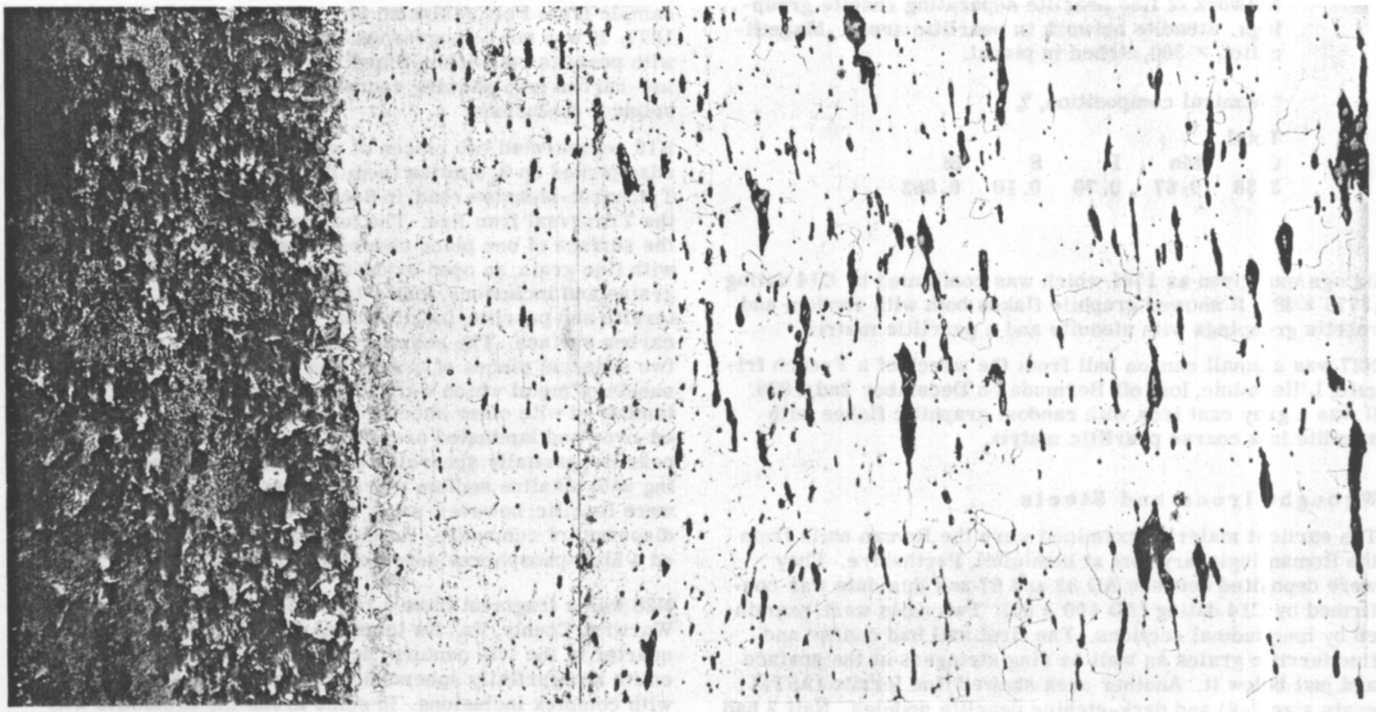

Fig. 5 — Sample N8: Italian sword. Age: Early 16th century. Carbon-14 date: Unavailable

Microstructure: Transverse section, with surface highly carburized, wrought-iron core showing very little carbide. Opposite surface deteriorated, but showed evidence of carburization. Magnification × 100, etched in nital.

Chemical composition, %

C	Mn	P	S	Si
0.10	0.02	0.246	0.025	0.123

Fig. 6 — Sample N19B: Iron hoe or adze picked up 8.6 miles from Bauis Trichardt along the Trichardt-Messina road. Age: Transvaal Iron Age. Carbon-14 date: Unavailable.

Microstructure: This tool appears to have been fabricated from sheets of metal which were folded over upon themselves and laminated with other sheets. The illustration shows a folded-over area. The microstructure consisted of ferrite, pearlite, partially spheroidized pearlite, and cementite. Etching with alkaline sodium picrate indicated that the bands were ferritic; however, some of the bands have a very fine dispersion of cementite. An etch with Stead's reagent indicated a high phosphorus segregation within the bands. Magnification × 50, etched with nital.

Chemical composition, %

C	Mn	P	S	Si
0.27	0.001	0.046	0.004	0.047

phase within the grains was unidentified but was possibly iron nitride. Gross oxy-sulphide inclusions were present and the sample appeared to be a carburized wrought iron.

N28 was a bolt from the wreck of the 'Virginia Merchant', lost off Bermuda in 1660. It had a ferrite-pearlite structure with coarse-grain low-carbon areas, fine-grain ferrite-pearlite areas, and segregated carbon-rich areas of pearlite. Some rather large inclusions appeared to be wüstite. The drillings were taken from a low-carbon area. N29 is from the Smithsonian Institute and is alleged to have been left in the Frobisher Sound area in 1587. It was thought to be of meteoric origin but it showed gross porosity and iron oxide and the microstructure consisted of large ferrite grains and fine pearlite. N29 was not similar to a sample of meteoric iron which the author once had the opportunity to examine in the past.

Sample N30 was a number of small nails or tacks from a chest which belonged to George Washington. It was made in 1776 and repaired in 1885. N30B gave a C14 date of 1776 and N30C, 1885. N30B and C were wrought irons showing very little carbide. The inclusions were very complex; probably silicate types in B and definitely containing some FeO-silicate in C. They appeared to have been made from different wrought irons.

DISCUSSIONS AND REMARKS

Iron, the smelted rather than the meteoric variety, entered civilization in Asia Minor. Credit for developing the art has been given to the Hittite civilization, a militant Indo-European people who settled in the area now known as Turkey around 1900 BC. However, evidence of iron smelting predating the Hittite civilization has been found in the Babylonian Dynasty of Hammurabi and in Northern Rhodesia.

Prior to the 15th century, two distinct techniques of refining iron ore and producing steel existed in the world. The West (i.e. from India to Europe) reduced the ore through a bloomery process which never produced a liquid iron although the product, a sponge iron bloom, had to exist in a mushy or semi-liquid state for a short time. The bloom was converted into wrought iron by reheating and forging, and a 'steel' could be formed by carburizing the wrought iron, which was generally a very low-carbon material.

Iron smelting in China developed along an entirely different line. As early as the 6th century BC, the Chinese were producing cast iron. They obtained steels and wrought iron by the indirect process of decarburizing the cast iron. Their ancient process was a forerunner of modern technology. Cast iron was not produced in the West until the late 14th and early 15th century and, strangely, the blast furnace in Europe appears to have developed without the influence or knowledge of the oriental technology.

The following remarks will concern only a portion of the samples examined. The microexamination and chemical analysis of the samples did not produce evidence which would compromise the reported archaeological age of the samples but, in fact, the microstructure and composition generally lent credence to the age.

The Roman nails are a good example of early Western technology. Both nails were wrought iron which had absorbed varying amounts of carbon when they were forged. The carburization did not appear to be deliberate. Transverse micro-specimens showed that the carbon had penetrated very unevenly from the forged surface, and only nail No. 2 showed a significant amount of carbon. The presence of pearlite in both nails indicates that the temperature achieved during forging exceeded 723°C.

Samples N5 to N9 are also an interesting group representing the state of the art in Italy and Germany during the 15th and 16th centuries. The sample of earliest age (N7), the Italian armour of AD 1400, was a wrought iron showing a lightly carburized surface. The German armourplate N6 which had an assigned age of AD 1550 showed a comparable microstructure. Whether the carburization was deliberate or accidental is a matter of conjecture. However, the Italian artefacts shown by N7 to N9 are about the same age as the German sample, and they show a definite metallurgical sophistication. The latter two, N8 and N9, were wrought irons which were heavily carburized on both surfaces, and then the surfaces were hardened by quenching. The Italian armour-plate of N7 was a high-carbon steel which could have been produced by the indirect process. Sample N11 could also represent the indirect process.

The tool N19 was fabricated by folding and forging and by laminating and forging. The technique is indicative of the ancient 'pattern forging'. The pronounced banding is probably a gross case of phosphorus banding. The Transvaal Iron Age is placed in South Africa dating from about AD 800.

The metallurgical technology of the Orient is represented by samples N3, N23, and N24. The most ancient is shown by N3 (Fig. 1). This fragment of cast iron was produced during the 5th century BC. Although the total carbon is characteristic of a hypoeutectic alloy, the microstructure showing primary cementite platelets is hypereutectic. The total carbon of sample N23 is the eutectic composition; however, the islands of graphite surrounded by primary austenite (now pearlite) indicate a hypoeutectic microstructure. The matrix of this sample is ledeburite, the eutectic structure. In either case, the total carbon analysis is probably correct, and the primary phase, austenite-graphite or cementite platelets, was determined by the cooling rate. The carbon-14 dating method indicated that the archaeological age of sample N24 was incorrect. The microstructure, a hypoeutectic white cast iron, was comparable to the other Chinese samples because of the cementite matrix and a similarity of composition.

The following conclusions can be drawn about this group of Chinese cast irons:

1. The temperatures attained during the refining process were greater than 1140°C.
2. The presence of a cementite matrix with a minimum of graphite in the microstructure indicates that each part was chill-cast. A clear chill zone generally only extends from $^{1}/_{8}$ to 2 in below the surface; thus, the castings were either small sections or the submitted fragments were from the surface of a large casting.
3. The ores were not exceptionally high phosphorus-bearing ores.
4. The low silicon content of the samples indicates a temperature ceiling in the refining process. In a modern blast furnace, the reduction of silica occurs in the bosh at temperatures greater than 1490°C. The Chinese samples were probably subjected to maximum temperatures of 1150-1270 °C. The same reasoning is true of the manganese content.

The North American cast irons by contrast were grey irons. Note that these more recently smelted ores resulted in cast irons with higher phosphorus, manganese, and silicon contents. However, even in this group, there were samples which had low manganese and/or silicon checks. The Winthrop charcoal-smelted cast iron N13 had a check analysis which was very similar to the modern coke-smelted cast iron N1. The Saugus Works cast iron N4 had the highest manganese content of all of the samples. The microstructure of the grey irons by comparison to today's commercial cast iron showed no control over the graphite shape or distribution, and the steadite phase was excessive.

The chemical analyses were extraordinary by today's standards. The carbon varied from very low in the tacks from George Washington's chest to very high in the Chinese cast iron. The carbon was so low in sample N3OC that the accuracy of the carbon-14 date is subject to question. In general, a carbon analysis from an ancient artefact could be very misleading because the microstructures showed that the carbon in some samples were greatly variable. Excluding the modern cast iron of N1 and a group of North American cast irons, the manganese content was generally less than 0.1% by weight. The phosphorus content showed great variability and so did the sulphur content but to a lesser extent. If the North American cast irons are excluded, the remaining samples showed the following range of composition:

Carbon	0.01 to 4.32%
Manganese	0.001 to 0.16%
Phosphorus	0.003 to 1.13%
Sulphur	0.004 to 0.067%
Silicon	0.02 to 0.41%

ACKNOWLEDGMENT

I want to express my appreciation to Mr U. T. Hill and the Chemical Department of Inland Steel for the chemical analysis of the samples. I also want to thank Mr C. F. Schrader, Manager of Quality Control, for extending the permission to use the facilities and equipment of the Metallurgical Laboratory.

A study of the chemical composition of pre-Roman ironwork from Somerset

WARNER HALDANE

SUMMARY

This investigation was designed to discover whether a relationship exists between the chemical composition and provenance of ironwork selected from sites of the Late Pre-Roman Iron Age of the Somerset Levels and adjacent areas, thereby laying the foundations for wider research into the organization of the iron industry of the West of England in the pre-Roman period.

The results showed that it was highly probable that a relationship between the composition and provenance of the ironwork exists, but the paucity of suitable material for sampling made it impossible to draw any further conclusions concerning the organization of the iron industry in Somerset during the Late Pre-Roman Iron Age.

INTRODUCTION

Trade has always been a subject of great importance to archaeologists. It not only gives an insight into the economic development of a community but also provides a useful guide to a community's horizons.

The present investigation was designed to pave the way for a series of studies into the organization of trade in ironwork in the Pre-Roman Iron Age of the West of England by discovering whether a relationship exists between the chemical composition and provenance of iron artifacts selected from the Late Pre-Roman Iron Age of Somerset.

The iron 'industry' of the Pre-Roman Iron Age in Britain has been the subject of numerous assertions, few of which have been in any way verified. The two conflicting, though not mutually exclusive, assertions of particular interest to this investigation are that:

(1) The iron 'industry' was a local affair supplying only the needs of a limited area.

(2) There were a few specialist centres supplying worked and unworked iron to a large area.

Evidence cited to support the first view generally includes cases where iron ore, originating from a particular source, is found on a site close to the origin, for example at All Canning's Cross (Cunnington, 1923); or where there exists evidence of small-scale smelting, either in terms of equipment—for example the furnace at Chelm's Coombe, Somerset (Tylecote, 1952, p. 195) or the tuyere fragments at Glastonbury (Bulleid and Gray, 1911, 1917)—or in terms of the final product, as in the case of the bloom from Wookey Hole (Balch, 1914, p. 87).

One of the principal pieces of evidence brought forward to support the second view is based on the distribution of the enigmatic objects termed 'currency bars' (e.g. Nos. 1, 2, and 28), which shows a marked concentration in the area of the Forest of Dean (Fox, 1940). It had, therefore, been frequently assumed that the currency bars had originated there, thereafter being traded over the extensive area in which they are found. It has been shown (Tylecote, 1962, Table 74), however, that some of the currency bars found on the Cotswolds contain appreciable quantities of phosphorus, an element almost totally absent from the ores of the Forest of Dean. It would appear, therefore, that this origin cannot be assumed for all currency bars and it may be doubted that they were significantly traded at all.

The problem of local consumption versus trade is, therefore, by no means resolved, but it is to be hoped that the present investigation may form the basis for the eventual elucidation of the controversy.

BACKGROUND OF THE INVESTIGATION

As this investigation is concerned with a comparatively limited area, throughout which the object types show very little internal variation, it is desirable to distinguish the objects on other than morphological grounds. Since the number of possible iron-ore sources is large in most parts of the British Isles, it was decided to distinguish the groups of objects on the basis of their chemical composition, assuming that the various ore sources of a region will tend to have characteristic compositions which will be reflected in the compositions of the objects derived from them. In theory it should also be possible to locate an ore source by examining the distribution of objects having a similar composition to one another. To characterize the composition of an object a particular interest was shown in those elements occurring in trace quantities (i.e. less than about 1%), as they offer the likelihood of a wide range of variation and have been successfully used for this purpose by students of copper alloys, obsidian, and pottery.

The use of trace elements to distinguish iron artifacts and to discover their origins is not without its problems, of which the principal ones are discussed below:

(1) An ore body may vary considerably in composition within itself, thereby giving rise to a number of apparently unrelated groups.

(2) The composition of the derived objects is likely to show a much greater range of variation than that of the composition of the ore, owing to the variability of the processes used to produce the iron. It is possible that the discrepancy between the composition of the derived objects and that of the ore might become so great as to make the source of the objects untraceable. For this reason, very little reference will be made to the origins of the groups of artifacts of similar composition, at least in the current investigation, and they will be treated as entities in themselves.

(3) A problem, arising from the one above, is the method of defining a group of objects of similar composition, since there will frequently be areas of overlap between adjacent groups. This will be discussed further in the context of the results of this investigation. It may be said at this point, however, that the selection must be largely arbitrary, the choice having to be made with respect to the archaeological data available.

(4) A less fundamental problem is posed by variation in composition within a single artifact. This can be due to three principal causes:

(a) Small-scale fluctuations in the production processes.

(b) The use of iron from more than one source in a composite object.

(c) The reforging of scrap metal from several different sources.

(a) can be alleviated by taking a number of samples from the same object, lumping them, and analysing the result. (b) can be treated as though there were more than one object to be sampled. (c), however, is more or less insoluble.

(5) A considerable practical problem is presented by the removal of samples from the iron artifacts, principally by the size of the sample that can be removed, since, as with all archaeological material, it is desirable to extract as little as possible from the object, in order to leave plenty for future study and a certain amount to display in the museum. A maximum of 0.5 g, was generally taken, made up of several smaller samples taken from various parts of the object. Owing to the small sample size, it was decided to use spectroanalytical techniques for determining the trace elements.

(6) One of the greatest practical difficulties of the investigation was posed by the small number of iron artifacts that could be examined from most sites and by the comparatively small number of sites which have yielded ironwork suitable for examination. This introduces, therefore, a very considerable possibility of statistical sampling error, since the objects chosen for sampling from a site may not be reliable representatives of the iron objects from that site. However, as the material is limited, there is little that can be done.

In theory, therefore, it would be expected that each ore source would be surrounded by a group of derived objects, whose composition would be similar and in some way related to the composition of the ore source. The principal purpose of this investigation is to discover whether these groups of derived objects exist by discovering whether there is a relationship between the trace-element content of an object and its provenance. A secondary aim, possible only if the area of study is large enough, is to delineate the distribution of any groups that are identified, since small compact groups would favour 'local consumption' whereas large diffuse groups would favour the theory of 'trade from specialist centres'.

THE INVESTIGATION

Area and Period of Study

In order to provide the possibility of a number of derived groups of artifacts for study, the area of study had to be big enough to include several potential sources of iron ore. Also it was desirable that the area should be large enough to include within it the entire distribution of at least some of the groups of artifacts.

It is also desirable to limit the period from which the material to be studied is drawn, in order to reduce the effects of any time-dependent variables, such as the changing use of ore resources, methods of distributing ironwork, and processes of manufacture.

The period and area chosen was the Late Pre-Roman Iron Age of Somerset, with attention focused particularly on the Somerset Levels and Mendip Hills (Fig. 1). This choice was made since the area contains a relatively large number of excavated sites of the Late Pre-Roman Iron Age, several of which have yielded ironwork, and also a number of possible sources of iron ore. Of these the principal ones are:

The Somerset Levels (bog iron)
The Mendips (principally hematites and limonites)
The Somerset Coal Field (ironstones, carbonates, and sulphides)
The Winford District (hematites and sulphides)

and around the periphery of the area many other sources exist in the Brendon Hills, the Blackdown Hills, Exmoor, and the Forest of Dean. There are also probably many more sources of iron ore in the area which would have been suitable for use in the Pre-Roman Iron Age, but which have not been recorded since their exploitation would not be considered feasible by modern standards.

The time range from which the objects for sampling were selected, was, as has been said above, defined as the Late Pre-Roman Iron Age. To convert this into terms of a particular type artifact, the life span of the decorated pottery known as Glastonbury Ware was chosen, since this material has been assigned to the desired period (Hodson, 1964). As a chronological marker Glastonbury Ware has the great advan-

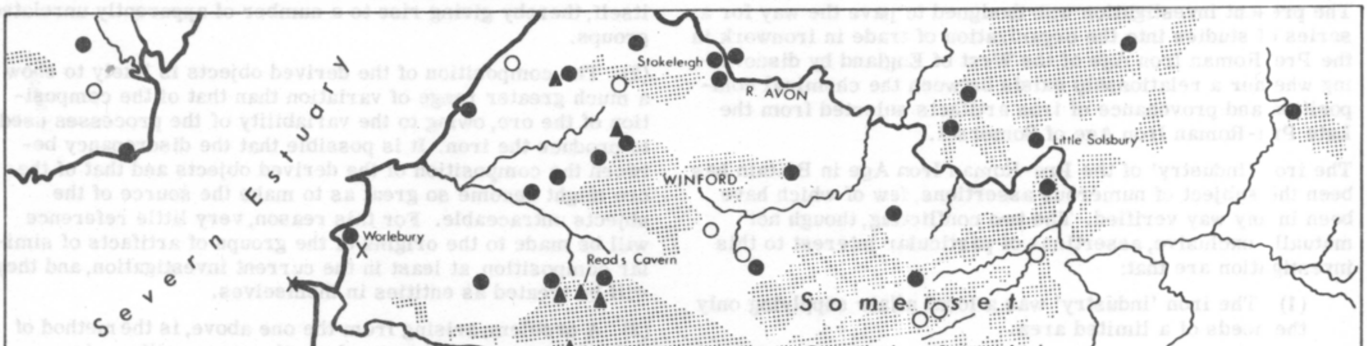

Fig. 1 — Pre-Roman Iron Age Sites in the Somerset Levels and Adjacent areas.

tages of a wide distribution throughout the south-west of England, where it appears to have been traded from a few specialist centres (Peacock, 1969) and of being associated at many sites with the controversial currency bars (Allen, 1967 p. 322). As far as possible only objects in primary association with Glastonbury Ware were chosen for sampling; however, at times it was necessary to accept for sampling material in association with particular object types known to exist in primary association with Glastonbury Ware at other sites.

The sites (see Fig. 1), from which material was selected, were Ham Hill, Meare Lake Village*, Glastonbury Lake Village*, Wookey Hole Cave, Read's Cavern, Worlebury Camp, Stokeleigh Camp, and Little Solsbury Hill Camp.

In order that the reader may appreciate better the origin of the objects selected (see Table I) in terms of the nature of the sites from which they came, there follow short outlines on the topography, geology and stratigraphy of these sites.

Ham Hill (NGR ST 485165): This large hill-fort (about 210 acres in area) is situated on a hill of Upper Jurassic shelly limestone (better known as Ham stone) at a height of some 300 ft above O.D. The currency bars (Nos. 1 and 2, Fig. 2) which came from a hoard of about 80 ploughed up in 1845 (Norris, 1846), were not directly associated with any other material. However, currency bars have been found associated with Glastonbury Ware at the site of Glastonbury itself (Bulleid and Gray, 1917, p. 395), and so these items have been accepted for the present study.

Meare Lake Village (NGR ST 446423): The site consists of two villages, East and West, the objects selected having come solely from the latter, which was excavated between 1910 and 1937 (Bulleid and Gray, 1948, 1953, and with Cotton, 1967). The West Village is situated on about 12 ft of peat and the vertical stratigraphy is generally poor. However, it appears that Glastonbury Ware existed throughout the entire life of the West Village so it is not unreasonable to assume an association between the material sampled and this ware. It should be remarked that a recent excavation of the East Village (Avery, 1968) showed that this part of the site was occupied for a considerable period before the appearance of Glastonbury Ware. This may result in a reappraisal of the stratigraphy of the West Village.

Glastonbury Lake Village (NGR ST 492409): This site, some 3.5 acres in area, is situated on an island of leafy peat in the more common rush peat of the levels and was excavated between 1892 and 1907 (Bulleid and Gray, 1911, 1917). Where the weight of the hut floors had caused the peat to be compressed, the hearths and floors had had to be replaced several times, thereby introducing excellent stratigraphical possibilities, which were unfortunately not fully realized in the report. Fortunately Glastonbury Ware seems to extend throughout the life-span of the site, so the finer points of stratigraphy need not concern us and all the objects selected for sampling can be assumed to be of the desired period.

Wookey Hole Cave (NGR ST 532480): This large cave is set in the Triassic Dolomitic Conglomerate and the Carboniferous Limestone against which it rests, where the River Axe emerges from the south face of the Mendip Hills. Excavation (Balch, 1914) showed that the principal periods of occupation were in the Pre-Roman Iron Age and the Roman Period. Glastonbury Ware extended throughout the Pre-Roman Iron Age levels, at the top of which was discovered a transitional La Tène II/III fibula and in which all the objects that were sampled were found, demonstrating that they are all of the Late Pre-Roman Iron Age.

Read's Cavern (NGR ST 468584): This cave site, set at the junction of the Carboniferous Limestone Z beds and earlier shales, was sealed by a large rock-fall. The assemblage of material showed little stratification and contained Glastonbury Ware, a plain dark burnished ware with bead rims, a transitional La Tène II/III fibula, a true La Tène III fibula (Langford, 1922, p. 139), and a considerable quantity of ironwork. No material from periods other than the Late Pre-Roman Iron Age was discovered, making this assemblage one of the most valuable of its kind. Sadly, this material suffered the effects of an incendiary bomb during World War II. Very great care was therefore taken during sampling to avoid superficial contamination.

Worlebury Camp (NGR ST 314625): This hill-fort is situated on a Carboniferous Limestone promontory overlooking the Severn Estuary and was excavated sporadically by numerous excavators during the 19th Century (Dymond, 1902). The bulk of the finds were extracted from the storage/rubbish pits cut into the rock and included both the artifacts sampled and Glastonbury Ware. Unfortunately, it is not recorded whether these objects were associated; however, as the contents of the pits appear to have been fairly uniform, it is not unreasonable to assume that the iron objects chosen for sampling come from the correct period.

Stokeleigh Camp (NGR ST 559733): This hill-fort, which occupies a heavily wooded spur of Carboniferous Limestone overlooking the Avon Gorge, was subjected to a series of small-scale excavations, initiated by the author in 1967. The single object (No. 20) from this site was associated with a coarse flat-bottomed buff pot of indeterminate type in a layer overlying one containing sherds of a plain dark burnished ware of a type similar to that found at Read's Cavern. It has, however, been suggested (ApSimon, 1969, p. 49) that this ware may have originated in the Early Pre-Roman Iron Age and be, therefore, a poor substitute for Glastonbury Ware as a chronological marker. Therefore, until the completion of the excavation, the date of this iron object is somewhat uncertain.

Little Solsbury Hill Camp (NGR ST 768678): This hill-fort lies at a height of some 600 ft above O.D., overlooking the City of Bath, on Middle Jurassic Oolitic Limestone. The excavations, carried out on a small scale between 1955 and 1958 (Dowden, 1957, 1962), revealed that the greater part of the occupation of the site had been during the Early Pre-Roman Iron Age. The objects that were sampled, however, lay above the main occupation levels and were separated from them by a sterile layer. No. 12 was accompanied by small fragments of pottery having the appearance of Glastonbury Ware, but which, it has been suggested (ApSimon, 1969, p. 48), may be derived from a pottery type of the Early Pre-Roman Iron Age of Wiltshire. Even with this possibility it seems probable that the objects are of the desired period.

Non-stratigraphical Factors Affecting the Choice of Ironwork for Sampling

Unfortunately, stratigraphical considerations are not the only ones affecting the choice of objects for sampling. Two other important factors are:

(a) The amount of residual iron in the object.

(b) The fragility of the object.

Every object for potential sampling was tested for its iron content with a permanent magnet. If too little was present to make sampling feasible, the object was discarded. The robustness of the object was assessed visually and it was found that a very high proportion of objects, acceptable on other grounds, had to be discarded because of fragility. In an attempt to reduce this loss a search was made for a suitable method to reduce the chances of disintegration during sampling. One of the more successful was embedding the object in an acrylic plastic used for mounting specimens for metallographic examination. However, if a sufficient thickness was used to perform the task effectively, it took several days in hot chloroform to remove the plastic after sampling. This was found to be impractical, especially in view of the fact that only a limited time could be spent at each museum.

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* The term 'lake village' has been shown by several authors (e.g. Avery, 1968) to be a misnomer. However, as the term is in common use it will be retained here.

TABLE 1 Objects selected for sampling

No.	Fig.	Description	Provenance	Museum	Sampling*
1	2	Part of currency bar.	Ham Hill (Norris, 1846).	Taunton.	See figure.
2	2	Part of currency bar.	Ham Hill (ibid.).	Taunton.	See figure.
3	3	Flat sub-rectangular object. Part of 4?	Meare (Bulleid and Gray, 1953 p. 240) No. I 61.	Taunton.	See figure.
4	3	Rod, rectangular cross-section.	Meare (ibid.) No. I 61.	Taunton.	See figure.
5	3	Earth anvil.	Meare (op. cit. p. 244) No. I 28.	Taunton.	See figure. (a) 0-0·3 cm depth* corrosion products. (b) 0·3-0·7 cm.
6	3	Earth anvil.	Meare (op. cit. p.244) No. I 32.	Taunton.	See figure. (a) 0-0·3 cm depth* corrosion products. (b) 0·3-1·8 cm.
7	3	Part of bar.	Meare (op. cit. p. 245) No. I 79.	Taunton.	In 1 place through thickness.
8	3	Part of chisel head.	Meare (op. cit. p. 246) No. I 35.	Taunton.	Along axis from principal fracture.
9	3	Part of file.	Meare (op.cit. p. 238) No. I 114.	Taunton.	See figure.
10	3	Part of bar.	Meare No. Y 111.	Taunton.	In 1 place through thickness.
11	3	Part of tapering rod.	Meare, West Village.	Taunton.	In 2 places.
12	2	Spearhead.	Little Solsbury (Dowden, 1962 p. 181).	U.B.S.S	See figure.
13	2	Knife blade.	Little Solsbury (Dowden, 1958 p. 25).	U.B.S.S.	See figure.
14	4	Part of handle.	Read's Cavern (Palmer, 1920).	U.B.S.S.	In 2 places on end opposite plate
15	4	Latch lifter.	Read's Cavern (ibid.).	U.B.S.S.	In 3 places on straight portion.
16	4	Looped rod.	Read's Cavern (Tratman, 1924 p. 126.)	U.B.S.S.	See Figure.
17	4	Part of rod.	Read's Cavern (Palmer, 1920).	U.B.S.S.	See figure.
18	4	Part of latch lifter.	Read's Cavern.	U.B.S.S.	See figure.
19	4	Hobbles. (owing to damage the open end is unclosable and vice versa.)	Read's Cavern (Palmer, 1920 p. 14.).	U.B.S.S.	See figure. (a) 3 places on open end. (b) 3 places on closed end.
20	5	Ring-bolt.	Stokeleight Camp. (see text).	U.B.S.S.	See figure.
21	5	Part of spearhead.	Worlebury (Dymond, 1902 p. 81).	Weston-super-Mare.	See figure.
22	5	Part of stake-head. (Figure after Bidgood.)	Worlebury (op.cit. p. 81).	Weston-super-Mare.	In 1 place near apex.
23	5	Part of knife blade.	Glastonbury (Bulleid and Gray, 1917 p. 381) No. I 4.	Glastonbury.	See figure.
24	5	Nail.	Glastonbury (op.cit. p. 389) No. I 59.	Glastonbury.	See figure.
25	5	Part of knife tang.	Glastonbury (op.cit. p. 382) No. I 45.	Glastonbury.	See figure.
26	5	Part of bill-hook blade.	Glastonbury (op.cot. p. 385) No. I 79.	Glastonbury.	See figure.
27	-	Bloom. 14 × 9 × 8 cm.	Wookey Hole (Balch, 1914 p. 87 & Pl. XVII (11).	Wells.	(a) 0-0·2 cm depth. (b) 0·2-1·9 cm depth.
28	2	Currency bar.	Wookey Hole (op.cit. p. 88.).	Wells.	In 2 places.
29	2	Bill-hook.	Wookey Hole (ibid.).	Wells.	In 2 places on the blade.

* An arrow or cross on a drawing marks the point from which a sample was removed.

U.B.S.S. = University of Bristol Spelaeological Society.

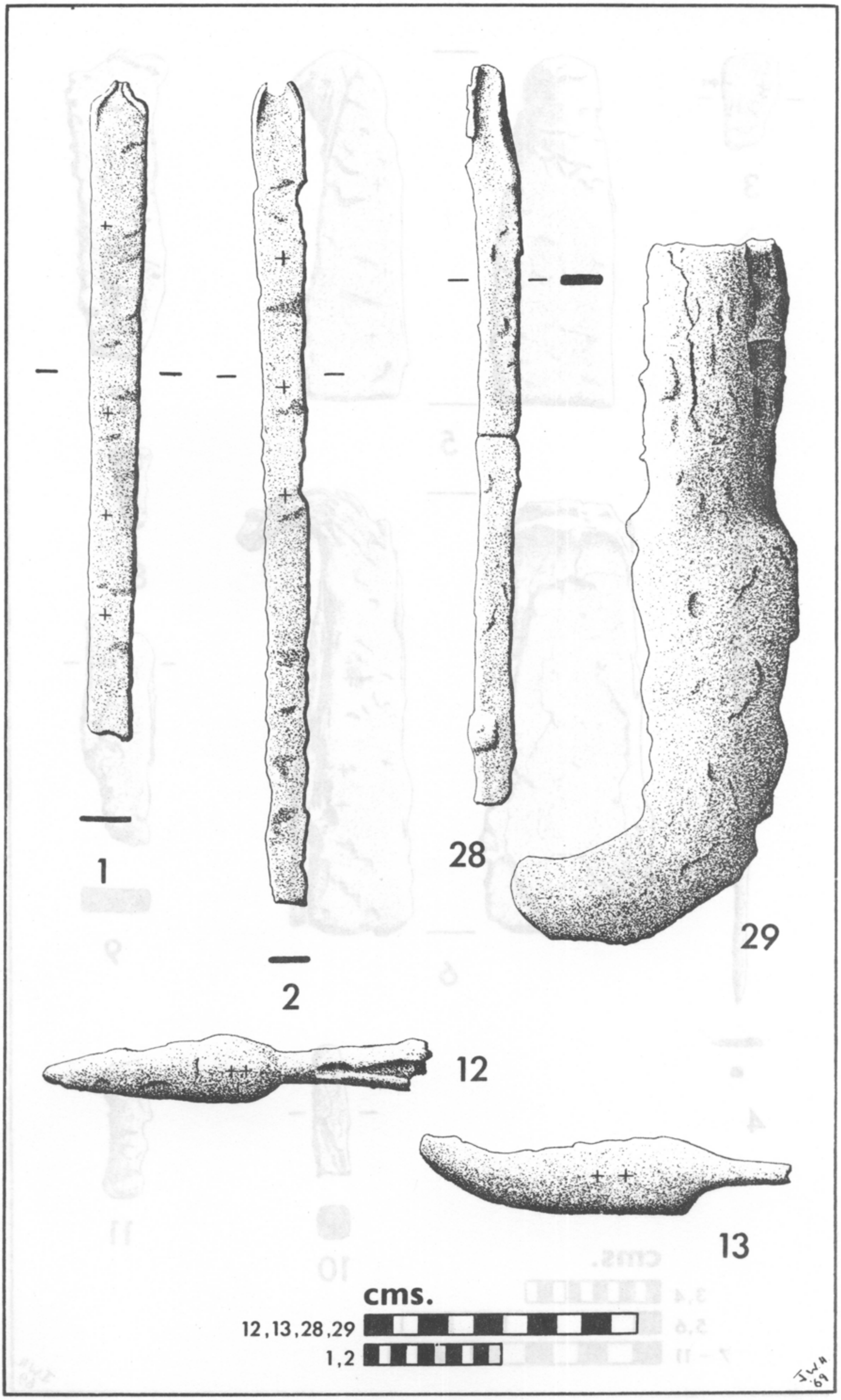

Fig. 2 — Iron objects from Ham Hill, Little Solsbury, and Wookey Hole.

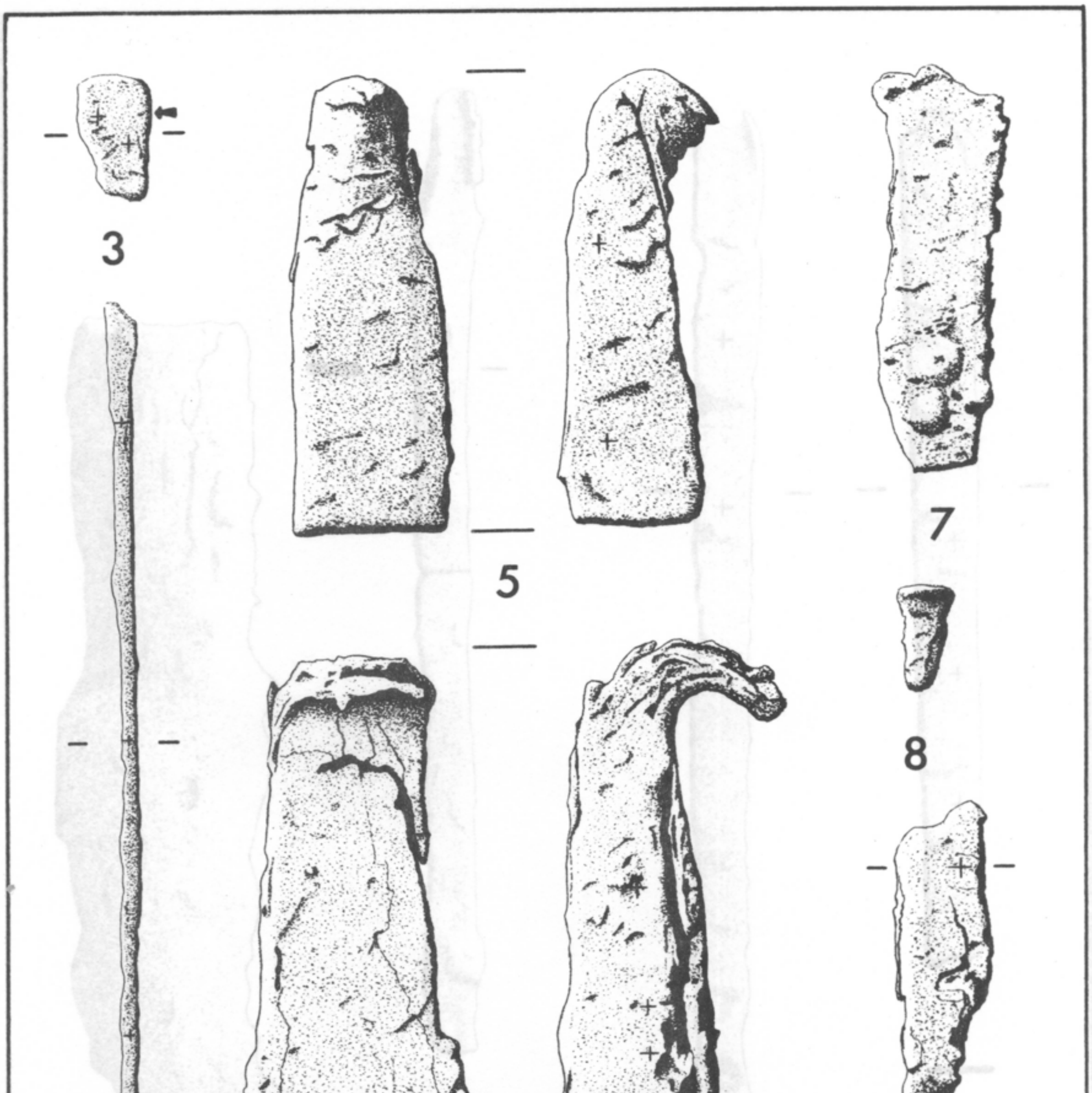

Fig. 3 — Iron objects from Meare.

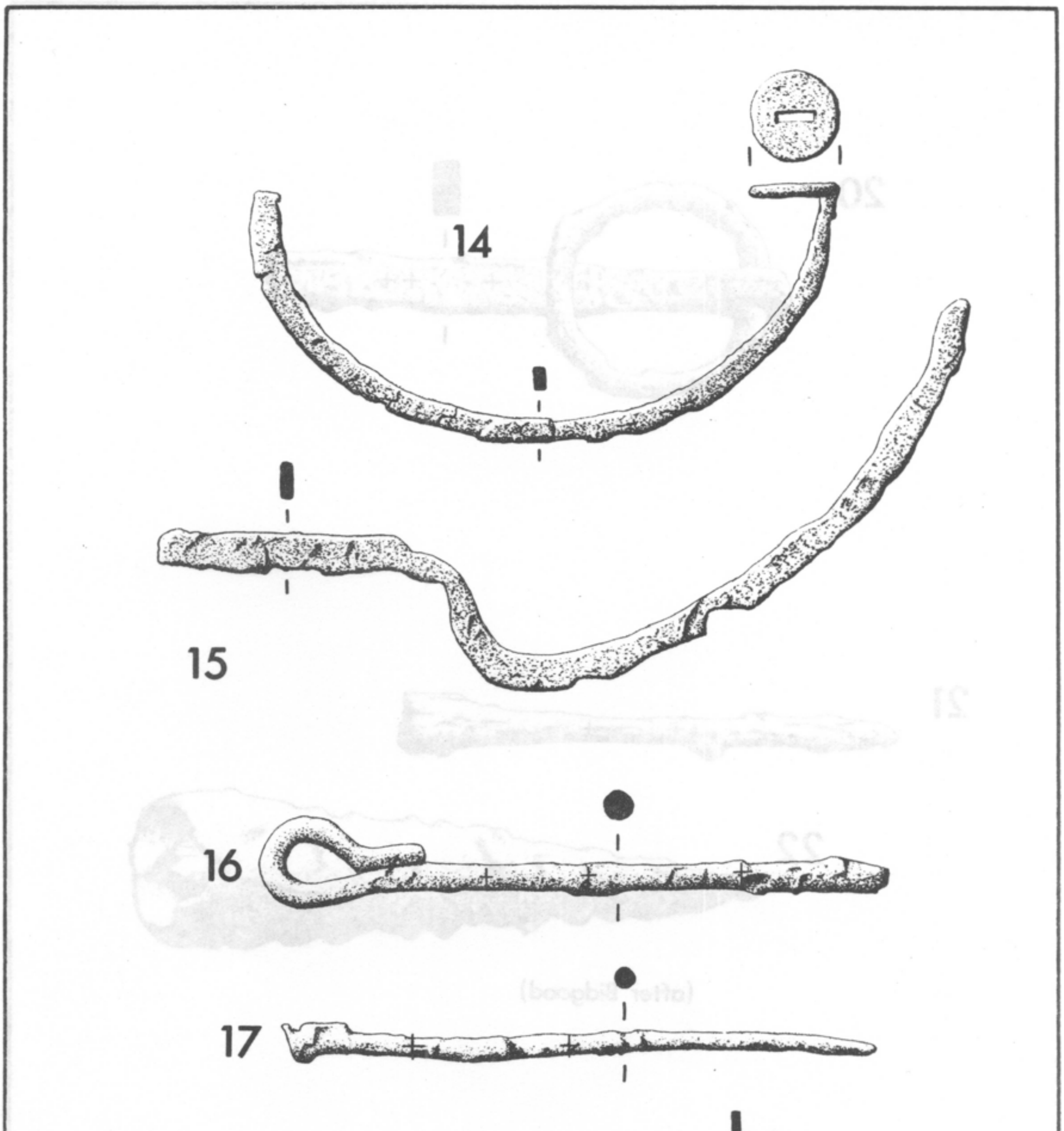

Fig. 4 — Iron objects from Read's Cavern

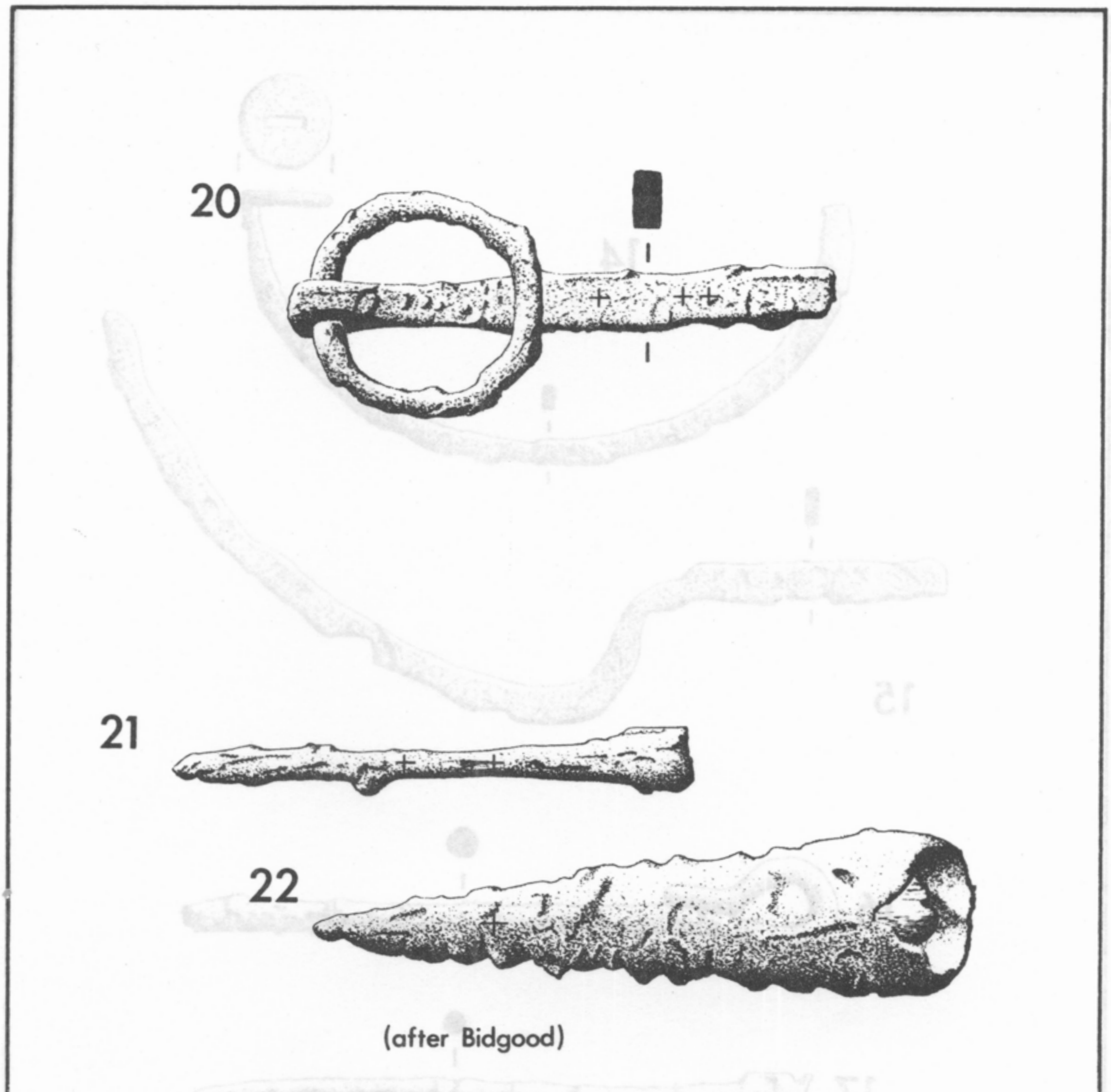

Fig. 5 — Iron objects from Stokeleigh, Worlebury, and Glastonbury.

The Removal of the Samples from the Objects

There are two major problems concerned with the removal of the samples from the objects:

(1) Obtaining a representative sample.

(2) Obtaining an uncontaminated sample.

The first has been mentioned above and can be readily alleviated by taking several samples from the same object and lumping them before analysis. According to information supplied by Mr P. S. Bramhall of BISRA-The Corporate Laboratories of BSC, Sheffield, spot analyses carried out on the cleaned surface of object No. 1 showed very little variation in composition, except in the cases of the elements silicon and aluminium. Obtaining an uncontaminated sample presents much greater difficulties, as there are several sources of possible contamination:

(a) From the corrosion products on the surface and in the interior of the object.

(b) From the drill-bit used to extract the samples.

(c) From chemicals used in the extraction process.

(d) From other samples, via the apparatus.

Of these, (c) and (d) can be eliminated by thorough cleaning of the apparatus. The importance of (b) was estimated by experiment, using the type of drill bit used to remove the actual samples on modern wrought iron and measuring the weight loss of the drill bit per weight of sample obtained. The result was 0.015%, which was considered to be negligible in the face of the much greater risk of contamination posed by source (a), though the risk of contamination from the drill bit might rise if the iron object contained a large number of slag inclusions. The surface corrosion products, which are liable to contain contaminants from the substrate in which the object was lying, are avoided without great difficulty by removing them from the area from which the sample is to be taken. Surface samples were taken from some objects to compare with those of the interior in order to discover the importance of superficial contamination. Interior contamination presents a much more serious threat as it will not only contain contaminants from the substrate but also from any subsequent conservation processes; since it is so intimately associated with the object, separation is virtually impossible.

Sampling Procedure

The following procedure was carried out for each object.

(1) The object was clamped in position in the work vice and drilled until bare metal was observed. The powdered corrosion products were then brushed away.

(2) Drilling was continued into the metal with a drop of distilled water surrounding the drill bit to assist the drilling and prevent the drillings from scattering.

(3) The drillings were transferred by means of an electromagnet to a filter paper in a filter funnel.

(4) 1-3 were repeated for several different places on the object.

(5) The total sample was washed with distilled water and ethanol, then dried and transferred to a sample tube. It was observed that, at this latter stage, most of the fine oxide particles remained on the filter paper. It is possible that this may have significantly reduced the risk of contamination from the corrosion products.

THE ANALYSIS OF THE SAMPLES

Choice of Elements for Determination

The range of elements used as a guide from which to make a choice were those elements determined in a series of wartime analyses of the iron ores of Britain (Groves, 1952), especial attention being paid to those of the south-west of England. The elements determined in that study (seldom all of them for a particular ore) were silicon, carbon, manganese, calcium, aluminium, magnesium, phosphorus, sulphur, barium, zinc, copper, lead, nickel, cobalt, titanium, arsenic, chromium, potassium, sodium, vanadium, and bismuth. Several of these elements were discarded from the present study: silicon, sodium and potassium owing to their ubiquity; carbon, sulphur and zinc because their proportions would be very severely affected by the smelting process; aluminium, phosphorus, and arsenic since their ranges of variation in the ores of the region of study were not sufficiently great to merit their determination by the proposed method.

The following elements were retained for determination: calcium, magnesium and barium, which, though widespread, do occur in pockets of high concentration in Somerset; manganese because it occurs in high concentrations in the Dolomitic Conglomerate (Kellaway et al., 1948 p. 86) and the ores of the Brendon Hills; nickel, cobalt and chromium since they exhibit a wide range of variation in the ores of the West of England; lead because of the very high probability of it occurring in the iron ores of the Mendips; copper, titanium, vanadium, and bismuth because they are unknown quantities, having been determined in a few cases. The resulting list of twelve elements for determination were: calcium, magnesium, titanium, lead, copper, nickel, manganese, cobalt, chromium, bismuth, barium and vanadium. Since many of these elements would survive principally in the slag inclusions within the iron objects, it was decided to perform a total analysis of both the iron and slag.

Analysis Procedure

The analysis of the samples was carried out by the firm of Waterfall and O'Brien of Bristol, and I am indebted to Mr C. S. Howes for the following information on the procedure adopted.

(1) 1% solutions of the samples were made up in hydrochloric acid.

(2) Any insolubles were treated with hydrofluoric acid to remove silica. The residue from this was fused with sodium and potassium carbonates, dissolved in hydrochloric acid, and added to the solution derived from (1).

(3) Calcium, magnesium, lead, copper, nickel, cobalt, manganese, chromium, and barium were determined directly in solution by atomic absorption spectrophotometry, using as a standard a solution of B.C.S. No. 260/2 (High Purity Iron) made up in the same way as those under test.

(4) Titanium was estimated colorimetrically using the peroxide complex. A known solution of titanium was used for reference.

(5) Vanadium was determined in the same solution as titanium, by the addition of fluoride ions.

(6) Bismuth was estimated visually using the iodide complex. Ascorbic acid was added to the solution to reduce iron and prevent the liberation of iodine. A solution of B.C.S. 260/2 with known additions of bismuth was used as a standard for comparison.

0·1%	V
0·03%	Ba
0·01%	Ti, Ni, Bi
0·003%	Pb, Mn, Co, Cr

The Results of Analysis

The analysis results are shown in Table II. Beyond the fact that chromium, barium, bismuth, and vanadium were undetected in all samples, that only calcium, magnesium, and copper were detected in all samples, and that some samples showed very high proportions of particular elements, little can be gleaned from an examination of the raw data. Since the purpose of the investigation was to discover whether a relationship exists between the provenance and chemical composition of the iron artifacts by means of studying the similarity between the composition of one artifact and another, it was necessary to obtain some measure of this similarity. Unfortunately, as the analysis of sample No. 13 was incomplete, it

TABLE II Analyses of samples from Late Pre-Roman Iron Age ironwork from Somerset, %

No.	Site	Ca	Mg	Ti	Pb	Cu	Ni	Mn	Co
1	Ham Hill	0.023	0.004	0.03	n.d.	0.015	0.024	0.003	0.015
2	Ham Hill	0.030	0.004	0.01	n.d.	0.017	0.014	0.003	0.004
3	Meare	0.030	0.005	n.d.	n.d.	0.050	0.015	0.015	0.026
4	Meare	0.008	0.001	n.d.	n.d.	0.032	0.017	0.010	0.017
5a*	Meare	0.019	0.006	n.d.	n.d.	0.16	0.075	0.020	0.096
5b	Meare	0.037	0.011	n.d.	n.d.	0.10	0.031	0.035	0.046
6a*	Meare	0.014	0.002	n.d.	n.d.	0.010	0.034	n.d.	0.004
6b	Meare	0.012	0.012	n.d.	n.d.	0.003	0.023	n.d.	n.d.
7	Meare	0.029	0.008	n.d.	n.d.	0.013	0.017	0.033	0.015
8	Meare	0.022	0.003	n.d.	n.d.	0.19	0.056	0.020	0.044
9	Meare	0.024	0.005	n.d.	n.d.	0.032	0.032	0.020	0.021
10	Meare	0.035	0.012	n.d.	n.d.	0.023	0.016	n.d.	n.d.
11	Meare	0.043	0.003	0.02	n.d.	0.007	n.d.	0.006	n.d.
12	Little Solsbury	0.029	0.007	0.03	0.003	0.019	0.019	0.003	n.d.
13	Little Solsbury	0.15	0.029	n.d.	0.020	0.052	0.02	0.008	N.S.
14	Read's Cavern	0.054	0.020	0.04	0.010	0.007	0.042	0.005	0.006
15	Read's Cavern	0.27	0.028	n.d.	0.32	0.011	0.032	0.007	0.089
16	Read's Cavern	0.062	0.007	n.d.	0.011	0.028	0.030	0.005	0.072
17	Read's Cavern	0.034	0.006	0.02	0.004	0.017	0.021	0.012	0.008
18	Read's Cavern	0.36	0.034	0.03	0.050	0.017	0.055	0.014	0.039
19a	Read's Cavern	0.071	0.023	n.d.	0.003	0.004	0.024	0.003	n.d.
19b	Read's Cavern	0.053	0.018	n.d.	0.003	0.016	n.d.	0.004	n.d.
20	Stokeleigh	0.032	0.008	n.d.	n.d.	0.001	n.d.	0.005	n.d.
21	Worlebury	0.025	0.004	0.02	n.d.	0.041	0.048	0.007	0.062
22	Worlebury	0.053	0.007	0.02	n.d.	0.022	0.036	0.018	0.034
23	Glastonbury	0.033	0.011	0.03	n.d.	0.016	n.d.	0.024	0.004
24	Glastonbury	0.045	0.003	0.01	n.d.	0.020	0.10	0.012	0.23
25	Glastonbury	0.046	0.014	0.04	0.003	0.014	0.064	0.013	0.032
26	Glastonbury	0.054	0.004	0.02	n.d.	0.075	0.026	0.020	0.018
27a*	Wookey Hole	0.053	0.016	0.01	n.d.	0.015	0.033	0.005	0.003
27b	Wookey Hole	0.043	0.008	n.d.	n.d.	0.004	0.036	n.d.	n.d.
28	Wookey Hole	0.10	0.008	0.01	n.d.	0.004	0.026	0.004	n.d.
29	Wookey Hole	0.060	0.011	0.03	0.009	0.045	0.025	0.005	0.003
DETECTION LIMITS		—	—	0.01	0.003	—	0.01	0.003	0.003

The following elements were undetected in all samples:

Chromium (<0.003), Bismuth (<0.01), Barium (<0.03) and Vanadium (<0.1).

n.d. = not detected. N.S. = no sample.

* Surface specimen. Rest, interior.

was necessary to omit it from further treatment of the results.

Though the analyses of the samples were quantitative, it was considered unnecessary, in this small-scale preliminary investigation, to subject the results to a fully quantitative treatment. The result for this investigation should show whether, when these readings are added to those of future studies, a more refined technique of treatment is desirable.

DETERMINATION OF THE SIMILARITY OF COMPOSITION BETWEEN SAMPLES

To reduce the range of variation to be covered by them, the readings were placed in logarithmic ranges, the lower ends of which depended on the limit of detection for the particular element. The ranges used were: for elements always detected and for those with a detection limit of 0·01%, less than 0·01%, 0·01-0·09% and greater than 0·1%; and for elements with a detection limit of 0·003%, less than 0·003%, 0·003-0·029% and greater than 0·03%. Elements undetected in all samples were not considered in calculating the similarity. Each range was then described by a two-character code, of which each character could exhibit two states, 0 and 1, by a process termed 'additive coding' (Sokal and Sneath, 1963). The result, starting with the lowest range, was 00, 10, 11. Thereafter the readings were assigned to their respective ranges, described by the two-character codes. In the cases of magnesium and titanium, the whole range of variation only resulted in the change of one character. Since it is important not to have any uniform characters running throughout the samples, these characters were omitted and the remaining characters for these elements were doubled in order to correct the weighting.

In the form of two-state characters, the content of each sample was compared with every other. Where either two 1's or two 0's coincided during comparison, a 'match' was scored, giving a total of 16 matches if the samples had an identical content. The value of the similarity was obtained as a percentage from the ratio of the number of matches to the total number of matches possible, namely 16.

The comparison of each sample with every other resulted in a matrix showing the degree of similarity between each sample. Because of its bulk, the matrix has not been reproduced but has been used as a basis for deriving groups of objects having similar compositions by a process called 'Complete Linkage Cluster Analysis' (Sokal and Sneath, 1963), one of the simplest of its kind.

First, nuclear clusters were formed of any items having a similarity of 100% with one another. Thereafter the level of

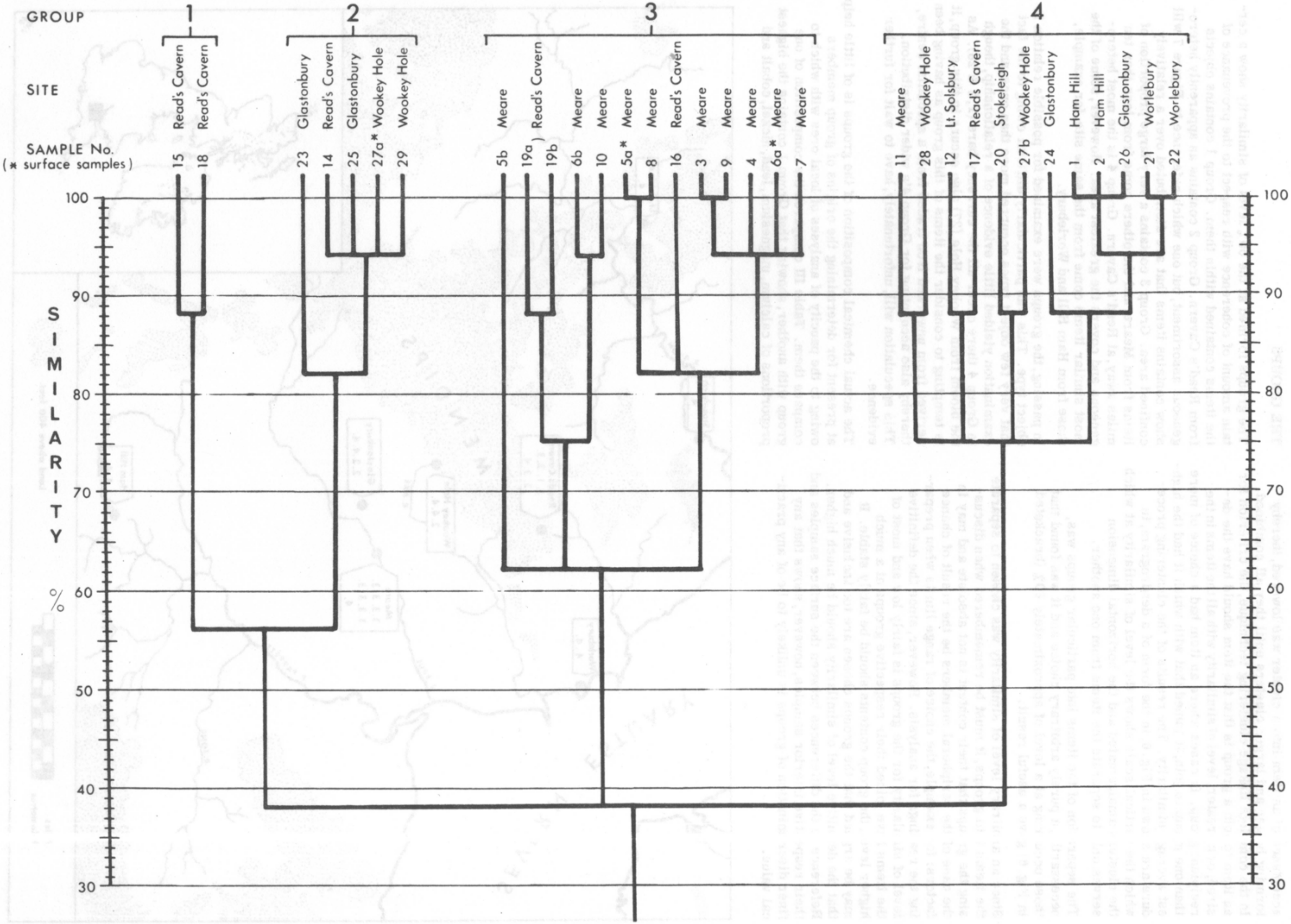

Fig. 6 — Dendrogram, showing similarities between the compositions of the samples and the groups, formed at the 60% level of similarity.

acceptance of an item into a cluster was lowered, thereby forming larger and larger clusters until they all combined. In the complete linkage clustering technique, the criterion for an item to join a group is that the item should have the desired, or a greater, level of similarity with all the items in the recipient group. In cases where an item had a choice of more than one group to join, it joined that with which it had the highest average similarity. The results of the clustering procedure are shown in Fig. 6, in the form of a dendrogram, in which the vertical scale shows the level of similarity at which the clusters amalgamated and the horizontal dimension serves only to separate the items from one another.

The separation of the items into particular groups was, necessarily, a purely arbitrary choice and it was found that those occurring at a level of approximately 60% (bracketed in Fig. 6) gave a useful result.

Since an arbitrary level of similarity was chosen to separate the items into groups, it must be remembered when discussing the groups that their content is not absolute and may in the case of the peripheral members be the result of chance factors: for example, the choice of range limits when preparing the readings for analysis. However, since the definitive level of similarity for the groups is fairly low and most of the items have joined their respective groups at a much higher level, the group contents should be fairly stable. It may be argued that the groups chosen are too inclusive and that the definitive level of similarity should be much higher. Reference to the differences between the surface samples and their respective interior samples, however, shows that any finer discrimination of groups is unlikely to be of any practical value.

THE GROUPS

The groups formed at the 60% level of similarity show a certain amount of coherence with respect to the provenance of the items contained within them. Group 1 contains objects from Read's Cavern. Group 2 contains an apparently heterogeneous assortment, but one which reference to Figure 7 will show contains items that are distributed over a relatively confined area. Group 3 contains a very large proportion of items from Meare, and the others come from less than ten miles away, at Read's Cavern. Group 4 is the most heterogeneous and covers the greatest area. However, some of the most similar items come from the same site, for example, those from Ham Hill and Worlebury.

In passing, the groups were examined for possible relation to object type. This was particularly difficult owing to the fact that very few object types occurred more than once, and the examination yielded little evidence of a relationship, though in Group 4 there occur all the currency bars (1, 2 & 28). As the bloom from Wookey Hole (27) also occurs in this group, it is tempting to consider the items of this group as having been derived from unworked iron traded from a specialist centre, thereby also accounting for Group 4's wider distribution. This speculation will, unfortunately, have to wait for further evidence.

The actual chemical composition of the groups is of little help at present for determining the origins of group members owing to the paucity of analyses of local ores with which to compare them. Table III compares the composition of one group with another, showing that Group 1 contains the highest proportions of calcium, magnesium, lead, nickel, cobalt and

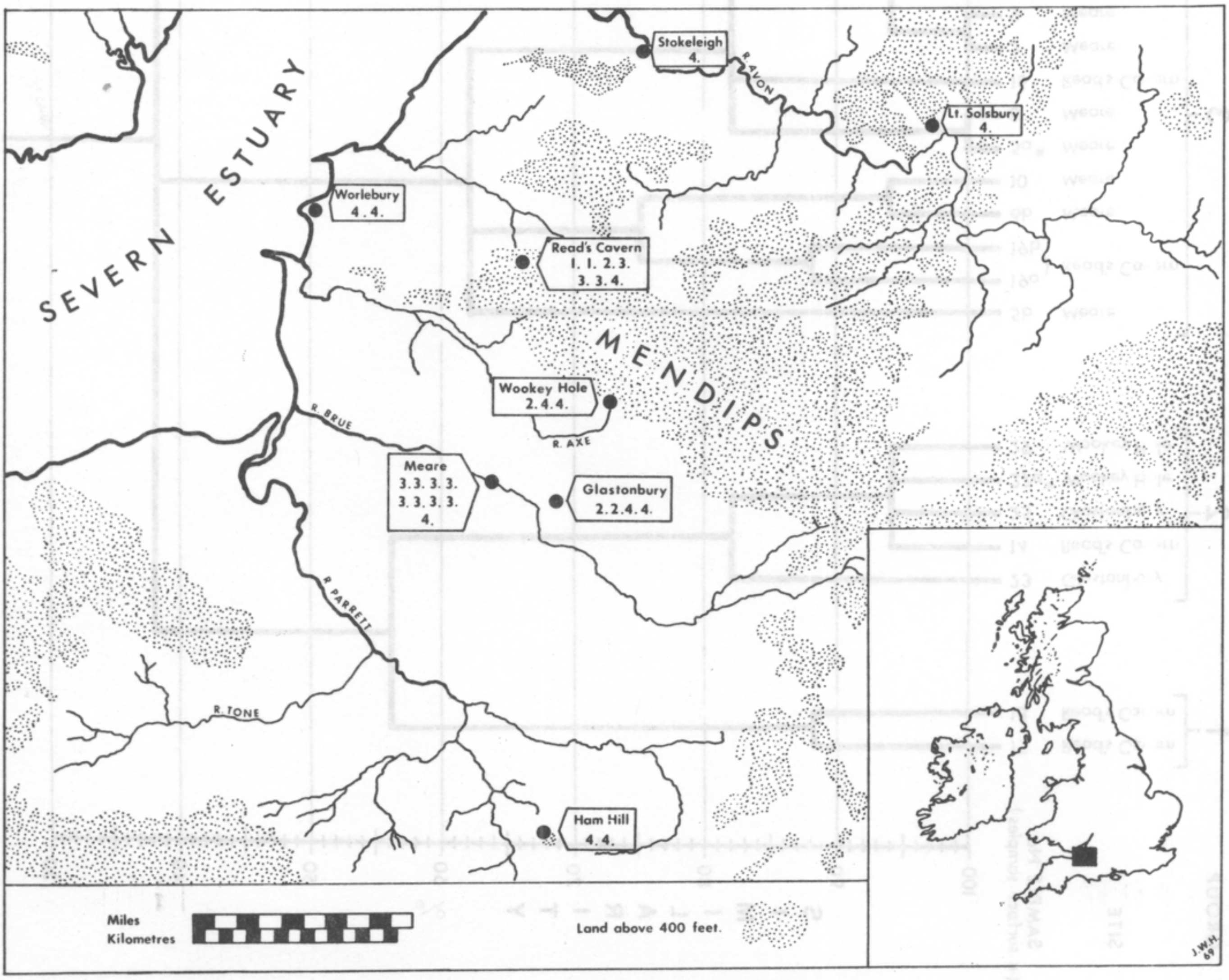

Fig. 7 — The distribution of the members of the groups, formed at the 60% level of similarity.

TABLE III Means of groups (formed at 60% similarity) normalized with respect to the overall mean and standard deviation, for each element.

	Ca	Mg	Ti	Pb	Cu	Ni	Mn	Co
GROUP 1	+3.56	+2.63	+1.0	+3.06	−0.41	+0.72	0.0	+0.80
GROUP 2	−0.10	+0.50	+2.0	−0.16	−0.30	+0.45	+0.67	−0.40
GROUP 3	−0.34	−0.13	<−0.5	<−0.20	+0.43	−0.11	+0.22	−0.02
GROUP 4	−0.18	−0.50	+1.0	<−0.20	−0.27	−0.06	−0.33	+0.09
Overall Mean.	0.056	0.010	0.01	0.014	0.032	0.031	0.011	0.028
Overall S.D.	0.071	0.008	0.01	0.056	0.044	0.018	0.009	0.045

the lowest of copper; that Group 2 has the highest proportions of titanium, manganese and the lowest of cobalt; that Group 3 has the highest proportions of copper and the lowest of calcium, titanium and is the joint lowest of lead; and that Group 4 exhibits no high proportions of any element, but has low proportions of magnesium, manganese, and lead.

The composition of Group 1 is of particular interest, with its high values for calcium, magnesium, and lead, since these elements suggest an origin for the group in an ore of the central Mendip region, where all these elements are abundant. The origin of Group 2 may lie in the proximity of the Dolomitic Conglomerate, which extends along much of the south face of the Mendips and contains a relatively large amount of manganese (Kellaway et al., 1948 p. 86). The origins of Group 3 and 4 must, for the present, remain even beyond the limit of speculation.

THE RELATIONSHIP BETWEEN THE PROVENANCE AND CHEMICAL COMPOSITION OF THE IRONWORK

Although examination of the distribution of the group members (Fig. 7) indicates that a relationship may exist between their composition and provenance, the result is not by any means conclusive. Fortunately, Group 3 contains such a large proportion of items from Meare that it is possible to estimate the probability of such a relationship existing.

Group 3 contains 8 out of 11 items from Meare (discounting the surface samples 5a and 6a) and, if it is assumed that every item has an equal probability of being selected (i.e. that there is no relationship between chemical composition and provenance), the probability of this group (which T-tests, performed for each element separately, show to be discrete from the other groups at a level of confidence of 0·12) being selected from a total population having 9 out of 29 items from Meare (discounting the surface samples 5a, 6a and 27a) is equal to:

$$\frac{C^{9}_{8} \times C^{20}_{3}}{C^{29}_{11}} = 3{\cdot}0 \times 10^{-4}.$$

Since the above probability is very low, the evidence would seem to favour the existence of a relationship between the chemical composition and provenance of the ironwork.

CONCLUSION

The results of the investigation showed that there is a high probability that a relationship exists between the trace-element composition and the provenance of ironwork from the Late Pre-Roman Iron Age of Somerset, thereby fulfilling the aim of the investigation.

Unfortunately, the secondary aim of the study was less sucessfully concluded, as the distribution of the groups formed at the 60% level of similarity could not be reliably delineated, owing to the small number of samples that could be obtained from any particular site and the wide spacing of the sites. It would appear, however, that the distributions of Groups 1, 2, and 3 lie within the area studied, whereas that of Group 4 extends beyond it. If the apparent distributions of the items of the former groups are a reliable estimate of their actual distributions, they would appear to favour an organization of the area's iron industry based on local consumption. Group 4's distribution might suggest organization on a wider scale, though it must be remembered that this group may consist of several smaller ones. The fact that all the currency bars fall within this group may be significant in this context.

Beyond the cases cited above, there appeared to be no evidence of any relationship between object type and trace-element content, but as few object types occurred more than once, the evidence was difficult to assess.

In this investigation the chemical composition of the items was used in a purely descriptive manner because so little is known about the effects of the production processes on the proportions of the trace-elements. An attempt has not, therefore, been made to relate the groups to any specific sources of iron ore, especially in view of the sparsity of analyses of local ores other than those of immediate economic importance.

It may be hoped that, now this method of studying trade in ironwork has been shown to be feasible, this investigation will lead to others over a much wider area and in periods other than the Pre-Roman Iron Age.

ACKNOWLEDGEMENTS

I would like to thank all those people whose help has been forthcoming during the performance of the investigation and the preparation of the subsequent report. Especial thanks are due to the following:

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Finally I should like to thank the Central Research Fund Committee of the University of London for their generous grant towards the cost of the research.

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Abbreviations

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P.S.A.N.H.S.	Proceedings of the Somerset Archaeological and Natural History Society.
P.U.B.S.S.	Proceedings of the University of Bristol Spelaeological Society.

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Notes and News

A SYMPOSIUM ON THE COMPOSITION AND ANALYSIS OF COINS

The Royal Numismatic Society is arranging a Symposium in London on Wednesday, Thursday, and Friday, December 9, 10, and 11, 1970, under the Chairmanship of Dr C.H.V. Sutherland, to discuss the various methods of analysing the metal contents of ancient and medieval coins. A number of scientists with experience of analytical work, from Great Britain and elsewhere, will each lecture on a different method of analysis, giving an exposition of the techniques they have used and the results they have achieved. It is intended to provide ample time for general discussion of the papers. Two rapporteurs, one a scientist and the other a numismatist, will sum up the discussions at the end of the Symposium. A volume containing the opening and closing statements, articles based on the papers delivered, and the rapporteurs' reports, together with bibliographical surveys of earlier work, will be issued as soon as possible after the Symposium in the Royal Numismatic Society's Special Publications series. It is hoped that the group of speakers as a whole will provide a good coverage of different methods of analysis, and that the resulting volume will serve as a useful work of reference.

Attendance at the Symposium, which is to be held in the rooms of the British Academy, Burlington House, Piccadilly, London W.1, is open to all who are interested. The registration fee of 7 gns. (£7.35) covers mid-morning coffee on each of the three days, a sherry party, and one copy of the volume of proceedings on subsequent publication.

Fellows of the Royal Numismatic Society, and others who are unable to attend the meeting, will be entitled to purchase copies of the proceedings at a special subscription price of £4.50 (or $12.50) payable before 31 December 1970. (The Society is unable to offer any commercial discount on prepublication subscriptions.)

Applications for enrolment together with the membership fee should be addressed to the Organizing Secretary, Symposium on Coin Analysis, Ashmolean Museum, Oxford, OX1 2PH. Cheques should be made payable to the Royal Numismatic Society.

Iron working at Meroë, Sudan

R. F. TYLECOTE

INTRODUCTION

The site at Meroë in the Sudan lies about 200 km north-east of Khartoum on the banks of the Nile and was for a time the capital of the Kingdom of Kush. During the 25th Egyptian Dynasty (751-656 BC) the Kushites ruled Egypt and adopted Egyptian ways. They were forced to retire during the 6th century BC when Egypt was attacked by the Assyrians. The 26th Dynasty under the Saites and Persians sent expeditions into the Sudan, and attacked the north. Gradually, either because of these attacks or the advance of the desert, the Kushites moved their capital from Napata in the north to Meroë. Here they established a flourishing city, with a Royal Palace, and they buried their kings and queens and some of their nobles under pyramids in the low hills which border the valley of the Nile in this area. These hills contain iron ore and it is possible that the smelting technique was learnt from Greek or Carian (Anatolian) mercenaries who accompanied the invaders on their attacks on the north.

While there is earlier evidence of the use of iron, traces of iron smelting do not turn up at Meroë until about 200 BC. However, the site is renowned for its large iron-slag heaps, one of which was cut through by the railway line from Khartoum to Wadi Halfa which was laid in 1897. It is clear that at one time this was the principal iron-making area of the Sudan, no doubt encouraged by the Royal House. A terminus post quem for the demise of part of the site at least is given by the building of the Lion Temple on one of the slag heaps to the east of the railway line. This temple was built between AD 246 and 266; soon after AD 300 Meroë was sacked by the king of Axum (part of modern Ethiopia), and iron working on a large scale was brought to an end. It is quite possible, however, that it continued spasmodically and on a much reduced level well into the Islamic period (14th cent. AD).

The site of Meroë is at present being excavated by P. L. Shinnie, Professor of Archaeology in the University of Khartoum, and it was through his kindness that I was able to examine the site and assist in the excavation.

IRON ORES

The sandstone hills of the northern Sudan are capped by an ironstone formation, and the pyramids of the northern cemetery at Meroë are built on and in this deposit of iron ore; this is a sedimentary deposit of varying ferruginous content interbedded with layers of more richly ferruginous and nodular material. On the site itself can be found large pieces of ore with a crenellated lamellar structure, and dark concretions and ironstone balls. Samples of both the lamellar and nodular types were taken for examination.

A large piece of lamellar ore weighing 2.23 kg and having a specific gravity of 3.27 was cut in two; a slice was removed from the centre and chemically analysed. The result is given in Table I. This shows an unexpectedly high silica and low iron content. As the loss on ignition is small it is neither a hydrate nor a carbonate and must be classed as a low-grade hematite. This piece must have been discarded as useless since the iron content of the slags on the slag heaps cannot be much less than this. Clearly, the silica must be in a very finely divided state as the grains cannot be seen with a hand-lens (x10).

A piece of the nodular ore which showed coarse silica grains underwent a loss of 12.5% upon ignition, and most of this was water. This is therefore in a much more hydrated condition (i.e. limonitic) and would make a more reducible ore if the silica content was low enough. It is not unusual to find that the ore on a smelting site is thus discarded, for obvious reasons. It is certain that some part of the deposit on which the northern cemetery lies is of sufficiently high grade for the direct reduction process which produces high-iron slags.

TABLE I Analysis of Sudanese Iron Ore %

Fe_2O_3	43.20
FeO	0.86
SiO_2	42.20
Al_2O_3	5.28
MnO	0.20
CaO	0.32
MgO	0.45
S	0.05
P	0.28
H_2O	0.48
Combined H_2O	1.18
	94.60

Hematite: Low grade.

A good deal of low-grade ore of a tabular type was used for building purposes. There were various examples in the Royal City, and also in the small settlement mound to the west of the Lion Temple slag heap.

GENERAL EXAMINATION OF THE SITE

A plan of the site is shown in Fig. 1. The Nile lies about 200 m to the west, and the most westerly group of buildings that can now be seen are those of the Royal City excavated by Garstang between 1909 and 1914. Between the Royal City and the railway line are a series of settlement sites, and some of those on the east side are topped with slag heaps of unknown depth. In some cases it would seem that the heaps were at first isolated, but later the settlement areas gradually extended towards them; in others the slag heaps have actually been built over earlier settlement areas. In the case of the central group, the settlement area was carried over the toe of the slag heap, while on the southern edge of NW 1 in the north-west group excavation revealed a furnace built into the remains of earlier buildings and overlain by later buildings. The East Heap clearly lies on top of a settlement mound, while SE 2 is almost all slag, as shown by the railway cutting.

EVIDENCE FROM EXCAVATION

Earliest Phase

Material from levels 6 and 7 in the trench to the west of Heap C 2 shows a more primitive character in the form of small furnace bottoms about 8 to 12 cm dia. and 3 to 6 cm deep. In this trench, level 9 has a C 14 date of 514 ± 73 BC; whilst producing metal, it did not produce any smithing or smelting refuse. However, level 8 has a C 14 date of 280 ± 120 BC. The furnace bottoms in levels 6 and 7 above could be either smithing or smelting debris, but for the fact that ore was found with those in level 7. This would seem to indicate that some of the bottoms originate from smelting. Very little tap slag was found in this deposit.

The smelting hypothesis was confirmed by the finding of a number of 'nodules' of rusted iron. These are now mainly magnetite, but have a core of residual iron and slag. The iron is mostly ferrite with nitride needles, and the slag is a typical smelting slag containing wüstite in a glass matrix.

Some larger furnace bottoms measuring about 19 × 17 cm across and 8 cm deep were found in the upper levels of the trench in the area of Heap C2. A furnace bottom of similar size was also found on the surface of the West Heap. These

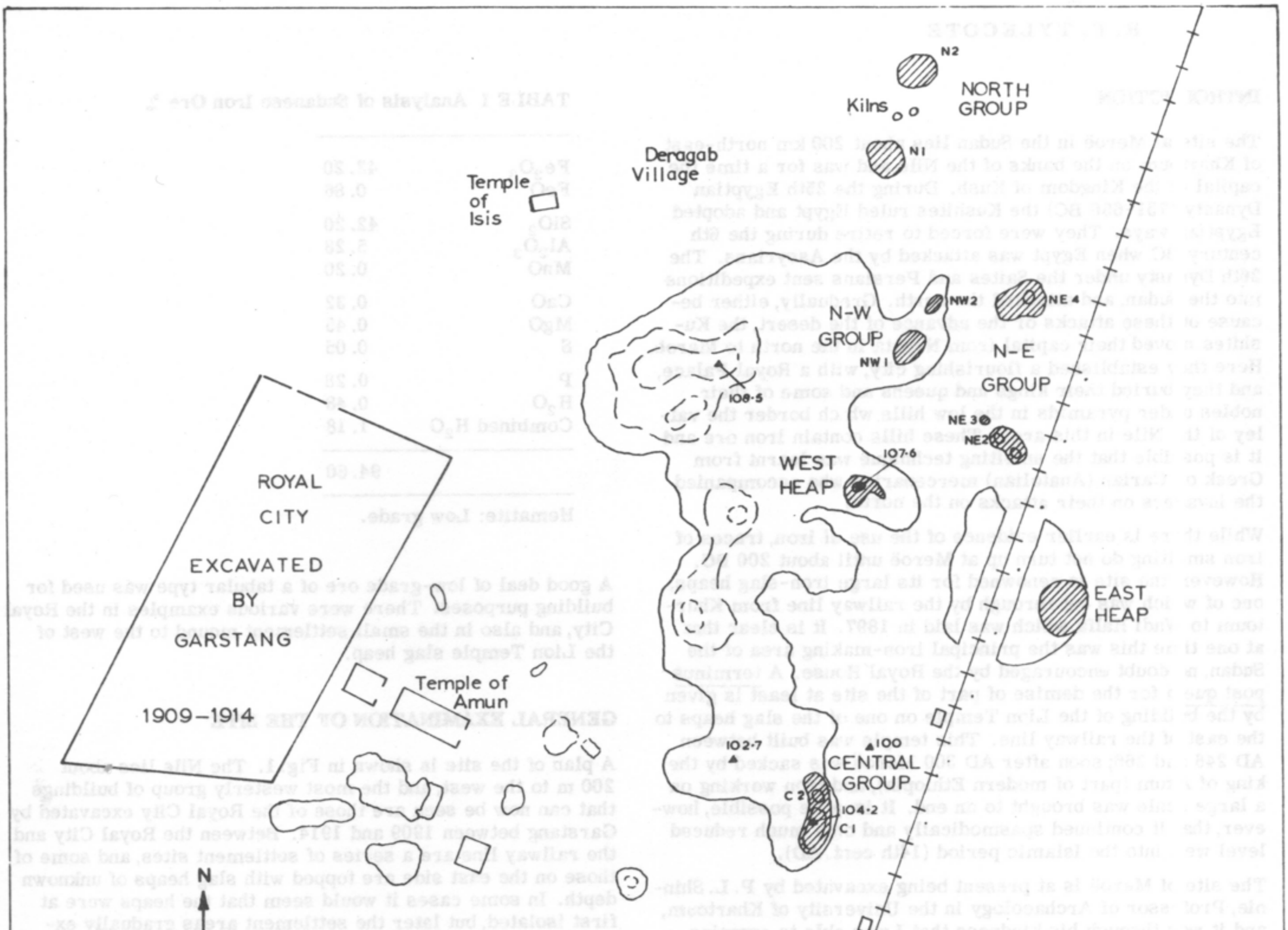

Fig. 1 – General plan of the site of Meroë

relate to the earlier phase of iron working on the site and are typical products of bowl furnaces.

From the technological point of view these bottoms are typical of the earliest phases of the Iron Age in Europe, and one would be inclined to date them about 200 years earlier than the sophisticated technique found over most of the site. They represent the slag accumulation in the bottom of bowl hearths 20 cm in diameter.

Towards the east end of this trench, the toe of a later slag heap comes into the section just on the natural subsoil level. This contains the usual furnace lining, tap slag, etc. of the main Meroitic period. It shows that unoccupied ground still existed at the east side of the site; this is probably why the heaps are mainly on this side.

Evidence from the Slag Heaps

All the large slag heaps seem to contain the same type of material on the surface, which presumable relates to one of the later phases of iron working on the site. The main items found were as follows:

(1) Large pieces of furnace lining with an internal diameter of about 0.5 m, vitrified and slagged on the inside but with red-burnt Nile mud on the outside. The thickness rarely exceeded 4 cm. One piece, excavated from the edge of slag heap C2, had two holes spaced 15 cm apart and of 12 mm bore. A small fragment had one hole 10 mm diameter on the vitrified side and 20 mm diameter on the other. These are the only pieces so far found on the site with small holes.

(2) Fired pottery tuyeres. There were many varieties of these (Fig. 2). The most frequent one was 60-70 mm o.d. and 22 mm bore (Type B); the bore was always parallel throughout its length, while the o.d. tapered at one end to give a wall thickness of only a few mm. The longest had a length of 40 cm. There were no indications of an enlarged bore to take the bellows nozzle, and it is therefore probable that this managed to fit into the 22 mm diameter hole; it is even possible that the back end tapered externally like the front end. The next most frequent type had the same o.d. but was 30 mm bore (Type C). One piece of a different type was found on slag heap SE2; this was square externally with rounded corners (Type D), 5.5 cm on the extant side and 23 mm bore. Many of the first type of tuyere (A, B, and C) were filled with slag for as much as 10 cm. This is very unusual (most tuyeres only show evidence of slag accretion at the ends) and means that the tuyeres could not be used after the slag had entered them.

The tuyeres had been made from the clay used for the rough pottery. Some showed signs of finger marks, and it was clear that they had been made by being pressed round a wooden rod that had been withdrawn before firing. Others had been smoothed before drying but still showed evidence of the use of wooden rods as formers which had been withdrawn from the wet clay.

(3) Pieces of dense tap slag that had solidified in a 'bowl' about 30 cm diameter. It was clear that the centre of these lumps had been more porous than the surface.

(4) Slag runners about the size of a wrist.

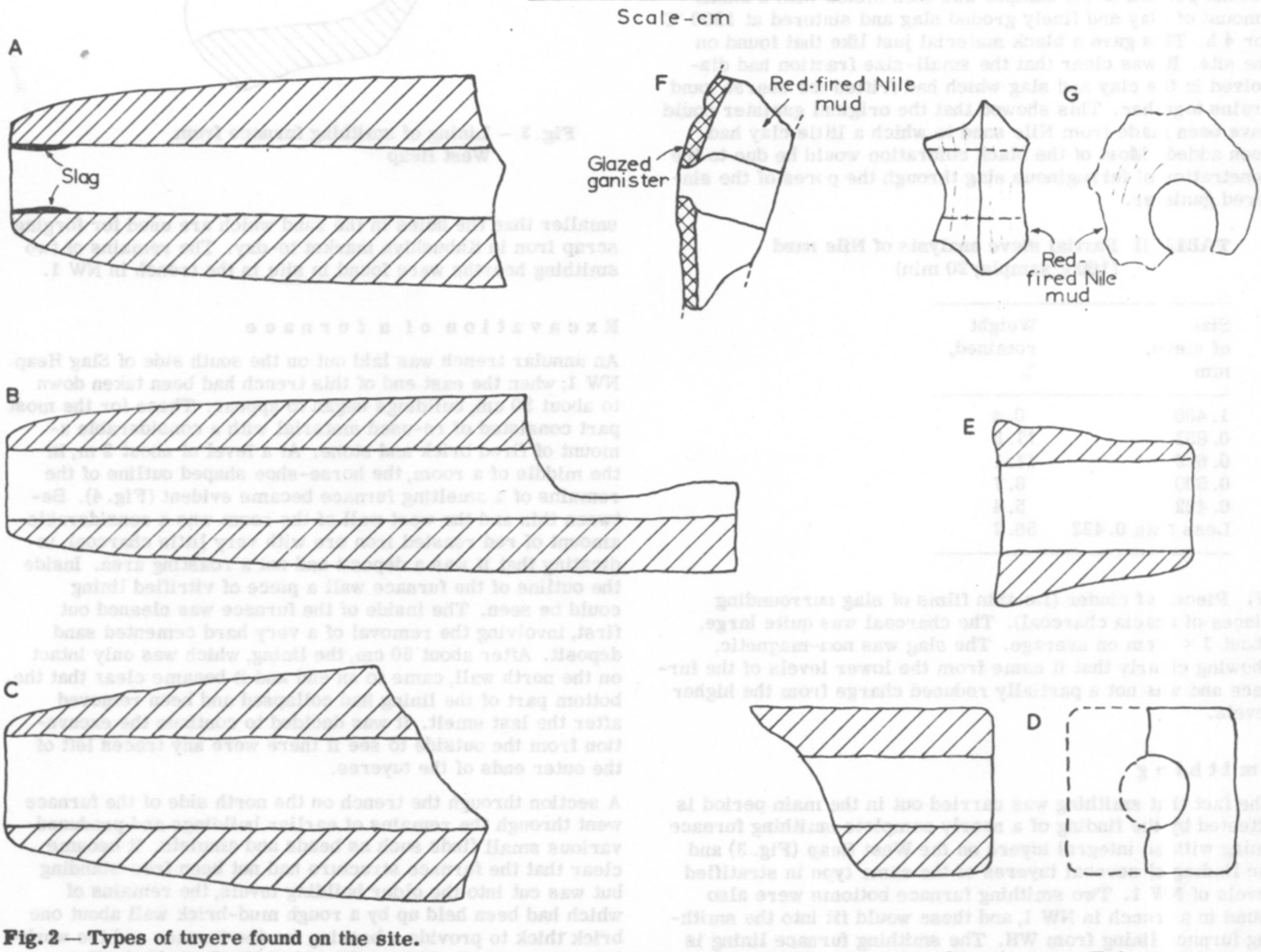

Fig. 2 – Types of tuyere found on the site.
Types A, B, C and E are all smelting furnace tuyeres. Type D, is probably from a smelting furnace. F, is an upper-level tuyere from a smelting furnace. G, is an unused tuyere from a smithing furnace.

(5) Large masses of tap slag weighing 5-10 kg had clearly been attached to the runners and had been formed by running downhill; some had run over a slope and others had fallen vertically, showing that the side of the slag pit was in some cases undercut. Both had solidified on the more or less level bottom of a pit.

Most of the slag found on the slag heaps was typical high-density tap slag, undoubtedly from the latest phase. One piece was examined and found to consist of fayalite laths and glass. The surface had oxidized on tapping and showed the presence of magnetite as fine dendrites and angular crystals. Naturally the surface was magnetic; the centre was almost non-magnetic.

(6) Large pieces of black ganister-like material that had probably resulted from the fritting of a mixture of coarse spherical sand grains with a small amount of clay. This could have been derived from the local sand by a winnowing process in which only the fraction above 0.5 mm had been retained. This material had been used for lining the bowl and the lower parts of the shaft. Many pieces showed considerable slag wash, some were slightly glazed, and others were rough. The nature of the frit was such that the slag lumps that formed the bowl could be easily broken away from it, leaving a thin layer of frit on the slag. Some of the pieces were angular, showing the nature of the junction between the bowl and the shaft.

As it appeared that the local Nile sand could have been used, a partial sieve analysis was carried out on a sample of sand taken from the original natural surface of the site about 10 m down from the top of the occupied levels. This gave the results shown in Table II, which show that it is a coarse sand with over 45% greater than 0.4 mm diameter. A portion of the whole sample was heated at 1200 °C but did not sinter. A second portion of the sample was then mixed with a small amount of clay and finely ground slag and sintered at 1200 °C for 4 h. This gave a black material just like that found on the site. It was clear that the small-size fraction had dissolved in the clay and slag which had fritted the coarse sand grains together. This showed that the original ganister could have been made from Nile sand to which a little clay had been added. Most of the black coloration would be due to the penetration of ferruginous slag through the pores of the sintered ganister.

TABLE II Partial sieve analysis of Nile sand
(100 g sample; 20 min)

Size of sieve, mm	Weight retained, %
1.400	0.4
0.853	17.8
0.699	11.1
0.500	8.7
0.422	5.4
Less than 0.422	56.2

(7) Pieces of cinder (i.e. thin films of slag surrounding pieces of acacia charcoal). The charcoal was quite large, about 3 × 3 cm on average. The slag was non-magnetic, showing clearly that it came from the lower levels of the furnace and was not a partially reduced charge from the higher levels.

Smithing

The fact that smithing was carried out in the main period is attested by the finding of a nearly complete smithing furnace lining with an integral tuyere on the West Heap (Fig. 3) and the finding of several tuyeres of the same type in stratified levels of NW 1. Two smithing furnace bottoms were also found in a trench in NW 1, and these would fit into the smithing furnace lining from WH. The smithing furnace lining is only 20 cm dia. and thus is very small, which suggests that only small artifacts were made in it. However, it is no smaller than the holes in the sand which are used for forging scrap iron in Kabushiya market to-day. The remains of two smithing hearths were found in situ in the trench in NW 1.

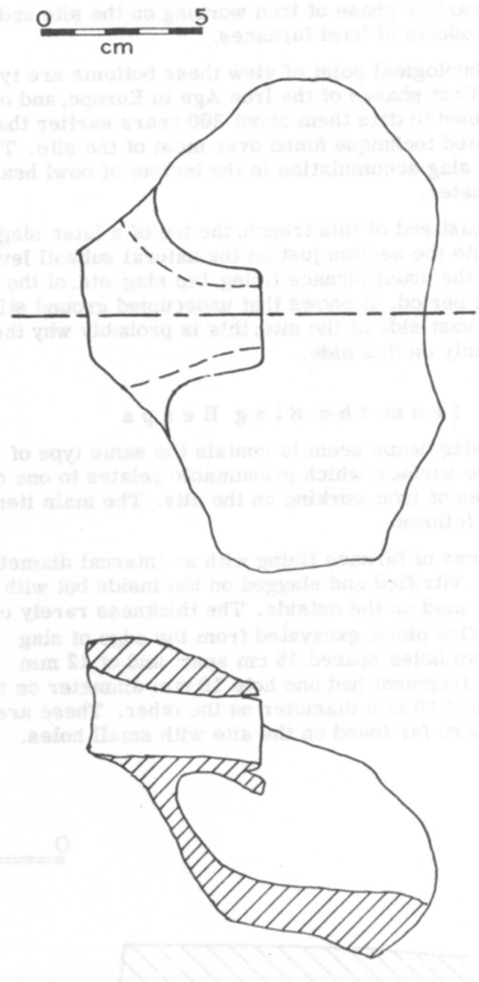

Fig. 3 — Lining of smithing furnace from West Heap

Excavation of a furnace

An annular trench was laid out on the south side of Slag Heap NW 1; when the east end of this trench had been taken down to about 30 cm, buildings began to appear. These for the most part consisted of re-used material with a considerable amount of fired brick and stone. At a level of about 2 m, in the middle of a room, the horse-shoe shaped outline of the remains of a smelting furnace became evident (Fig. 4). Between this and the west wall of the room was a considerable amount of red roasted iron ore with very little charcoal, indicating that it was a deposit and not a roasting area. Inside the outline of the furnace wall a piece of vitrified lining could be seen. The inside of the furnace was cleaned out first, involving the removal of a very hard cemented sand deposit. After about 50 cm, the lining, which was only intact on the north wall, came to an end and it became clear that the bottom part of the lining had collapsed and been removed after the last smelt. It was decided to continue the excavation from the outside to see if there were any traces left of the outer ends of the tuyeres.

A section through the trench on the north side of the furnace went through the remains of earlier buildings and produced various small finds such as beads and amulets. It became clear that the furnace structure had not been free-standing but was cut into the older building levels, the remains of which had been held up by a rough mud-brick wall about one brick thick to provide a backing for the furnace and the working area in front. This wall had been built to a height of at least 1 m.

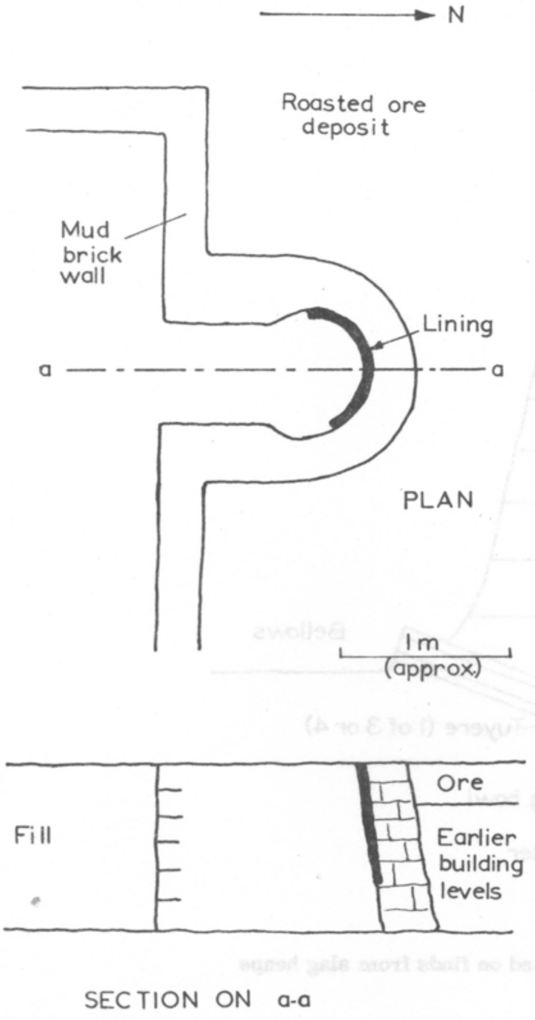

Fig. 4 — Sketch plan of furnace excavated on the southern side of Heap NW 1 (not to scale)

Unfortunately the furnace bottom was missing and no tuyeres were found in situ. Apart from the fact that the furnace was not free-standing, the only additional piece of evidence obtained in this area was the finding of a large section of vitrified lining in situ, which shows that the internal diameter of the furnace at a height of about 0. 9 m above the bottom was about 0. 5 m and that the shaft had a considerable inward slope. It would seem very difficult to place tuyeres in the back or sides of such a furnace, which leaves us with two possibilities: (1) all the tuyeres were placed in the front wall, or (2) there were at least two types of furnace.

The furnace found seems to have been very similar to the 2nd century AD furnace from Ashwicken, Norfolk, which had a single opening in the front wall about 30 cm high and 30 cm wide. At Meroë there would also have been other free-standing furnaces with tuyeres distributed round the circumference, possibly at two levels as shown in Fig. 6.

The layers of roasted red ore to the west of the furnace went down into the building levels, showing that there had been smelting in the area prior to the erection of the furnace found. The roasted ore which alternated with grey layers of clay-sand varied in size from about 8-20 mm, and was soft and friable. As is usual on early sites, it was still magnetic, showing that the roasting had not gone to completion. But it was highly permeable and would be very satisfactory for smelting after some further breaking up to give a consistent size of about 8 mm.

The slag heaps overly the latest building level in the smelting area, thus showing that smelting continued after the excavated furnace had fallen into disuse and had been succeeded by a later building. While this furnace is by no means the latest evidence of iron-working on the site, it was certainly not the earliest both on typological and stratigraphical grounds. We do not yet know the latest period of iron working on this site: it may well go into medieval times. This furnace can almost certainly be dated to the principal period of iron working, i.e. the first two centuries AD.

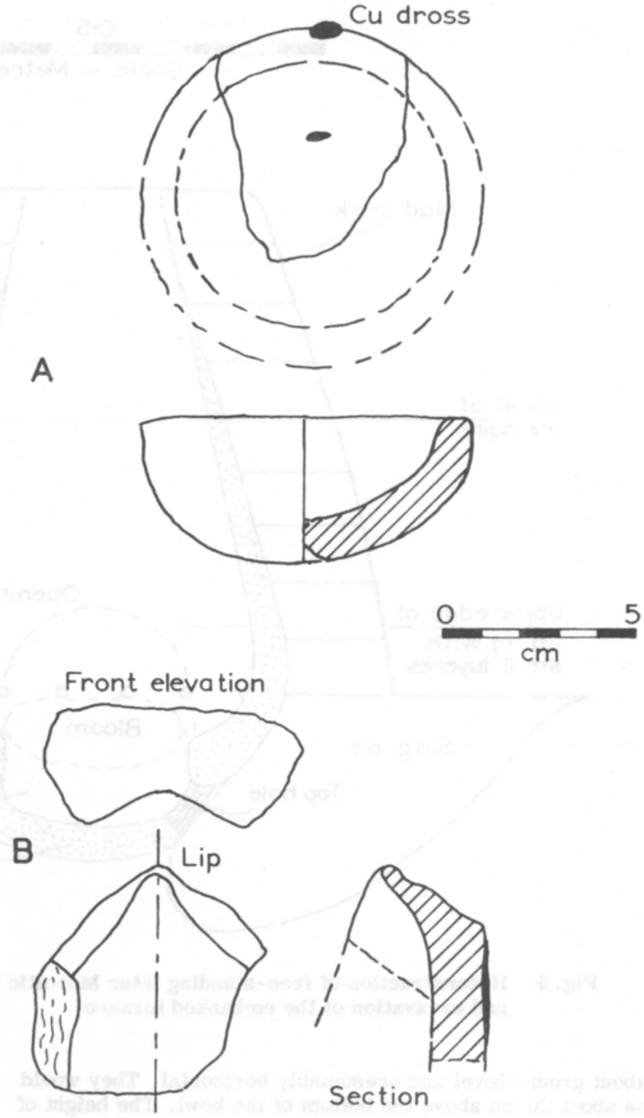

Fig. 5 — Crucibles: A, unstratified from Heap NE 4; B, stratified; from the south side of NW 1

Two crucible sherds were found which show that non-ferrous metal working was also practised on the site. The first (A in Fig. 5) came from Heap NE 4; it is a typical shallow hemispherical crucible of Nubian or Roman type. It contained some copper-base alloy dross. The second (B) is from a flattish-bottomed crucible with a pronounced lip. Apart from the lip, this crucible would have been circular. There was no internal deposit, but the bottom was vitrified with wood ash.

Reconstruction of Furnace

The typical free-standing furnace (probably of the period 50 BC to 200 AD) was a shaft furnace with a bowl for the receipt of the slag before tapping (Fig. 6). The pottery tuyeres entered the bowl at a slight angle to the ground and must have been at least 40 cm long. The bowl was about 45 cm dia. and 10 cm deep. The higher-level tuyeres, made by making holes in the inside surface of the lining and perhaps joining these to pieces of the standard 20 mm bore tuyere, were at

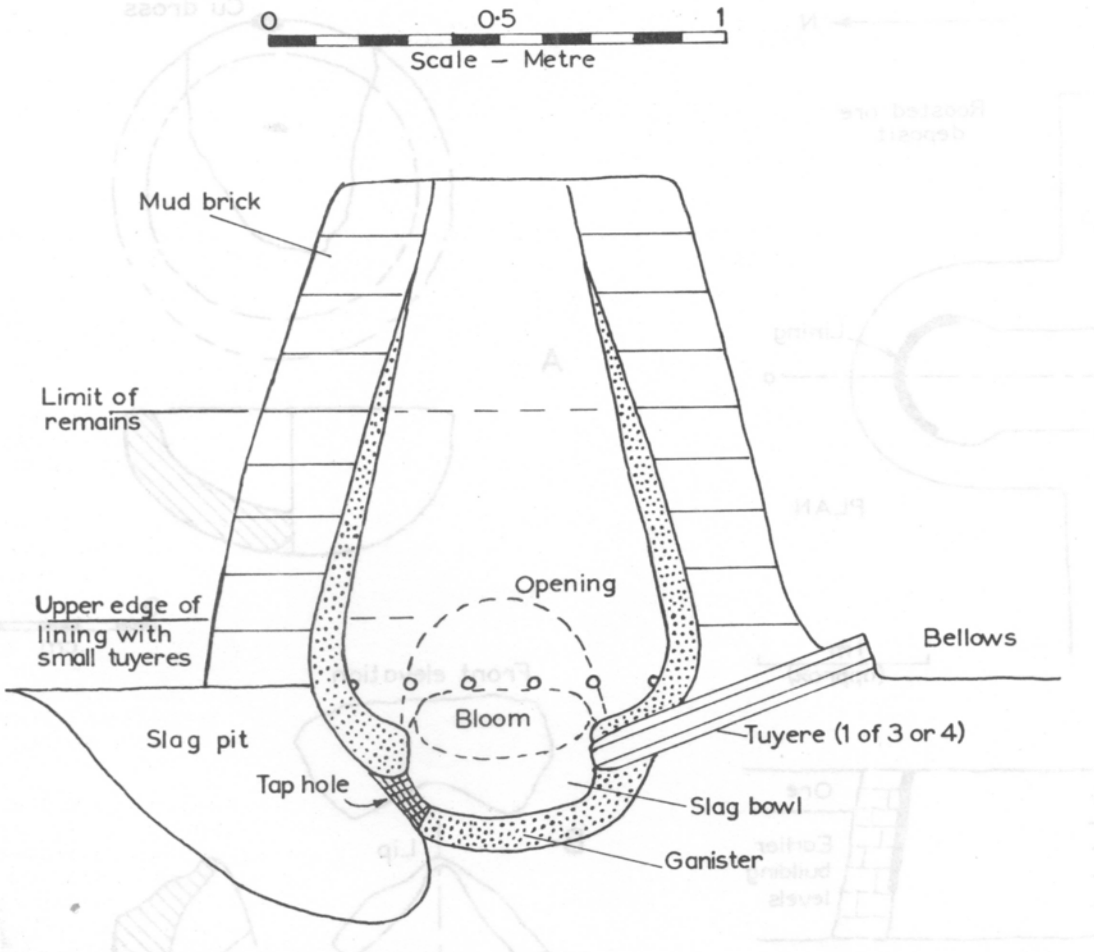

Fig. 6 — Reconstruction of free-standing later Meroitic furnace. Based on finds from slag heaps and excavation of the embanked furnace

about ground level and presumably horizontal. They would be about 20 cm above the bottom of the bowl. The height of the shaft would be about 1 m above ground level and the inside tapered slightly inwards. It would have an internal dia of 0.7 m at the bottom and 0.3 m at the top. There would be about 12 high-level tuyeres and probably three of four low-level ones. It is most probable that the furnace was bellows-blown, mainly because of the frothy nature of the slag round the end of some of the tuyeres and the very high temperatures obtained.

The working of the furnace would be as follows. The furnace would first be filled with charcoal which would be ignited by putting a small piece of glowing charcoal down one of the tuyeres or through the bloom withdrawal opening in the side. Blowing would start at once and only when the contents of the furnace had reached a good red heat throughout would charging of ore start. Charcoal and ore would be charged alternately in proportions of about 1 to 2 parts of ore to 1 of charcoal by weight. In actual practice, volume measures would be used. After a time the bowl would fill with slag and this stage would be noticed by the tuyeres tending to fill with slag. The slag would then be tapped through the wrist-sized hole in the side into the pit and the bowl would be more or less empty; some of the tuyeres would be stopped up and unusable. Blowing would then be transferred to the higher-level tuyeres; the bloom would begin to form below them and the slag to liquate from the underside of the bloom into the bowl. This could probably be emptied a second time, but since the most of the heat would now be around the higher-level tuyeres this is not very likely; once the bowl was full of slag the process would be finished.

The bloom would then be withdrawn by crowbars or timbers through a side hole at about ground level. It would be stuck to the ledge of the furnace, but its removal could probably be assisted by an upward thrust with a bar through the taphole. The bloom would be about 25 cm dia. and about 20 cm deep. It would consist of porous iron low in carbon with some charcoal and slag, particularly on its outer surface. This would be knocked off, and the rough bloom sent to the smiths for cutting up and for forging into smaller and denser pieces. This would be done in small 15 cm dia. hearths with a single tuyere such as was found on the West Heap.

This reconstruction is based on the evidence cited above and personal experience in working a bloomery furnace with a single tuyere. It could be wrong in some details (for example, the double-level tuyere arrangement is unique) and only excavation of a complete furnace can confirm it.

ACKNOWLEDGEMENTS

I am greatly indebted to Professor P. L. Shinnie and the University of Khartoum for allowing me to examine the site and for their hospitality. I would also like to thank Margaret Shinnie for her help in many ways and for allowing me to use her plan upon which Fig. 1 is based; and the University of Newcastle upon Tyne for a grant towards my part in the project. Some of the information in this report was provided by Catherine Hills and Ahmed Mohamed Ali, to whom I am extremely grateful.

Spring Meeting of The Institute of Metals

REPORT ON THE SESSION ON HISTORICAL METALLURGY HELD IN THE CONVOCATION HALL, CHURCH HOUSE, LONDON, S.W.1. ON 12 MARCH, 1970.

This is the first time that the H.M.G. has been asked to speak about its work to one of its sponsoring bodies. After an introduction by the President of the H.M.G., M. M. Hallett, George Parker gave a talk on 'A metallurgist looks at the Bronze Age' (a summary of this paper follows this report). It is a good example of the applications of metallography to early bronzes and shows how much information can be obtained by the use of relatively simple and standard techniques.

After this, R. F. Tylecote followed with a description of early metallurgical sites in the near East. He started in Israel where he showed examples of copper smelting hearths starting from the Chalcolithic period through the Late Bronze-Early Iron Age transition to the Romano-Byzantine period. The methods of ore-getting and dressing were also illustrated. This was followed by a description of gold-ore grinding mills in Afghanistan. Returning through Iran, he showed as an example the method of extracting zinc as zinc oxide or 'tutty' as practised in the 13th and 14th centuries AD and recorded by Marco Polo and others.

According to Hamd-Allah Mustawfi in AD 1340, zinc ore was got from the mines as a heavy mineral which was moistened and made into the form of bars. These bars, when dry, were put into a furnace to extract the 'tutty' or ZnO. The bars, which were rather like sword sheaths, were then taken out.

At Deh Qualeh enormous quantities of broken bars were found which seemed to be the residue of this process. About a kilometre to the SE of the village, willemite was found in the spoil heaps of an abandoned mine. A piece of the latter with its ochreous gangue was ground up, mixed with about 2% clay, and moistened. The paste was then moulded into a bar about 5 cm long and 1 cm dia. This was dried in air and placed in a retort with charcoal, heated for 18 h at 1150°C, and the distillate collected at the mouth of the retort tube. A fair amount of water was seen to come off; no doubt some of this was from the clay but most of it would be from the limonite gangue.

The distillate was analysed and found to consist of 92.5% ZnO, the rest being CO_2, showing that some carbonate was present. The composition of the prepared ore would be as follows: ZnO, 18.5%; H_2O+CO_2, 24.1%; residue (mainly Fe_2O_3), 57.4%. The composition of willemite is Zn_2SiO_4 and it contains 58.3% Zn. The Zn content of the ore is 14.9%, and therefore the ore would contain about 25% of the mineral.

There was obviously no difficulty in extracting zinc oxide from this ore; the temperature and conditions used would be perfectly possible in the 14th century. The bars would be strongly heated with charcoal and bellows at the bottom of a hearth or furnace and the zinc oxide would condense on to the sides or other parts of the furnace. It might well have had a horizontal flue. The 'tutty' would be scraped off the sides or flue and could be used to make eye ointment as recorded, or more likely to make brass. In the latter case it would be used like calamine and put amongst the lumps of copper and charcoal at the bottom of a crucible.

A small amount of slag would form during the heating of the bars from the wood ash and other material. The bars remain intact after the process. At first they were magnetic, showing the presence of reduced iron, and this could be oxidized by further heating in air. At Deh Qualeh, however, this would have happened during the 500 years since they were made. The bulk of the slag on the site came from the extraction of other metals such as copper and lead, not from the extraction of zinc.

Although there are one or two occurrences of zinc as a metal in its own right in the Greco-Roman world, it is generally thought that up to some time in the Middle Ages the metal as such was unknown and that all brass was made by the 'calamine' process. In the museum at Ludlow, Salop, two pieces of metal which have been identified as zinc have recently come to light. Typologically these are undoubtedly medieval (12th cent.); they may be one more piece of evidence of the manufacture of zinc in this early period in the western world or they may possibly be metal imported from the east which has been recast.

After these two contributions on the non-ferrous side, Henry Cleere of The Iron and Steel Institute followed in order to show the meeting some of the things that had been happening in the ferrous field. While a good deal of experimental work is going on in various laboratories of the world in order to try and understand the bloomery or direct process for the production of iron, the archaeologists feel that this should be supplemented by field studies utilizing local resources. Cleere described what he had been doing regarding the techniques used in the Weald. He had built and operated a small low-shaft bloomery furnace based on those found in the area around Bardown in Sussex dated to the Roman period. He used local carbonate ores, roasted them in a trench-type roasting furnace, smelted them with various charcoal/ore ratios, and had produced a bloom containing about 10 kg of iron. He had managed to tap a quantity of slag having the right structure. From the metallurgical point of view the roasting had not been very efficient, but it had served the purpose of making the ore more friable. It is probably that this is all that roasting did in antiquity and that the more complete oxidation was carried out on the finer material in the upper levels of the smelting furnace. He had found that turf was the most convenient material for sealing the tap hole; this burnt through gradually and allowed the hot slag to run out without too much heat loss.

(Much of the work in Israel has already been published in the J.I.M. 1967, 95, 235-243. It is expected that a full report on the expedition to other parts of the Near East will be published during the summer in 'Metals and Materials'. Henry Cleere's report was published by The Iron and Steel Institute in February, 1970, and a condensed version will appear in Britannia, vol. II, 1971.)

A metallurgist looks at the Bronze Age

GEORGE PARKER, B.Sc., Ph.D., A.R.P.S.

The writer's approach has been almost entirely that of a metallurgist, and was initiated in the early 1950s when H. H. Coghlan, F.S.A., F.R.A.S., Hon. Curator of the Borough Museum, Newbury, Berks., courageously provided for detailed examination (which implied their destruction as display specimens) four artefacts which in type and composition spanned the whole period of the Bronze Age, from, say, 1800 to 500 BC. This choice exactly foreshadowed a more detailed table published in R. F. Tylecote's 1962 book, 'Metallurgy in Archaeology', much referred to in this paper.

These objects comprised, in chronological sequence, a pure copper flat axe; a halberd blade in a Cu-2.2% As-1.1% Sb-0.4% Ag alloy, with three pure copper rivets through its tang; a 12.6% Sn-0.8% Pb bronze winged and looped palstave; and a 9.3% Sn-3.2% Pb bronze looped and socketed axe.

In addition to the examination of this material, which is still continuing as there is often enough sound metal available to permit, for instance, determination of work-hardening curves, other artefacts have been investigated using a more limited sampling technique which allows of their virtually invisible restoration.

Published compositions, for example those in Tylecote, indicate a comparative scarcity of pure copper products; however, in addition to the Newbury axe and halberd rivets, flat axes from Devizes and Somerset County Museums were similarly found to be of a composition which approaches that of tough-pitch high-conductivity copper. The writer surmised that this indicated remelted native copper as the source most likely to give such purity, but in discussion Tylecote and C. S. Smith agreed that oxide ores were also a possible source. All these copper artefacts were fully wrought, their microstructures being twinned alpha grains with the evidence of cold-work where most expected, i.e., towards the cutting edges of axes, and in the well formed hemispherical heads of the rivets. In the Somerset axe, with the cutting-edge specimen showing a hardness as high as 124 HV$_1$, the work-hardening was seen to be near the limit since elongation and apparent fragmentation of the cuprous oxide constituent, and possibly microcracking, had led to slight but elongated corrosion penetration of the cutting edge. Oxide distribution, usually in the form of residual networks, and central shrinkage cavities, in the rivets, were the only signs remaining of the cast state.

By contrast, two tin-bronze flat axes from Bristol were much nearer the cast state, with microstructures showing coring and alpha-delta eutectoid. Hardness values were evidence in each case of cold-working. In the cutting edges, some flow in the structure and hardnesses approaching 200 HV$_1$ indicated that cold-work had been concentrated there, clearly to harden and sharpen the edges. A ferric chloride etchant also revealed, in addition to the cored structure, very small twinned alpha grains. This structure (which, like others, is found more often than expected, once it has been seen) is now regarded as being caused in the cooling cycle of the cast metal, when shrinkage stresses are relieved by recrystallization in the still relatively hot metal. One of the axes had broken across the middle, its butt end being missing. There was gross porosity in the region of the fracture.

The halberd blade was again a wrought product, the thick central rib being little removed from the fully-annealed condition, whilst the tang, tip, and edge fins all showed cold-work. The hardness readings on the cutting edges were as high as 186 HV$_5$ compared with cracking limits of 191 HV$_5$ and 205 HV$_5$ established in cold-hammering and rolling tests, respectively. The rivet holes had been pierced through the hardened tang, and there was a slight indication that some form of drilling operation had been used. The grouping of As, Sb, and Ag as alloying elements is one often found at various concentration levels, and could come from fahlerz ores. However, as yet, chemists have made little progress towards emulating the petrologists' success in tracing artefacts back to their prime source. Of course, unlike metals, the stones are altered merely in shape and not in chemical and physical properties during the production processes applied to them. The marked improvement in mechanical properties given by alloying copper with As has caused Maréchal to draw a close comparison between As and Sn as alloying elements in copper.

Well defined traces of a parting line indicated that the palstave had been cast in a symmetrical bivalve mould. Save for a few blowholes and a spongy zone in the thickest section, the metal was sound. Again, the microstructure was virtually as-cast, with some areas of the very small twinned alpha grains, and evidence of cold-working at the cutting edge. Here, there was intercrystalline and slip-plane corrosion, of a type mentioned by E. Voce as evidence of existing cold-work. This view is confirmed by dislocation theory (J. Nutting, private communication).

The socketed axe showed many deficiencies with a substantial crack in the blade, and a sizeable hole through the bell, on the very obvious parting line, just in front of the loop. This hole is associated with a hot tear following the parting line on the interior of the bell, the mouth of which was misshapen in a way showing that the two halves of the bivalve mould had not mated exactly. The metal was very porous throughout, so the whole impression was of a casting poured from a grossly overheated 'wild' melt. This axe showed very markedly a phenomenon referred to by Voce as 'destannification' because of its rather similar appearance to the dizincification effect in brasses. In this example, the copper 'islands' appeared both in the surface of the metal and well within it (though the extensive porosity might well have connected such internal copper 'islands' with the surface). Copper deposits were also associated with what appeared to be an interdendritic nonmetallic eutectic of light and dark grey constituents. Electron probe microanalysis, kindly provided by the University of Aston in Birmingham, indicated this eutectic to be as high as 42% Sn. MacPhail is studying this 'destannification' and seems close to a satisfactory explanation of it.

Whilst the tin-bronze artefacts already discussed were all near the as-cast state, a fine double-edged tanged knife from Wells Museum has been found to be a fully-wrought product, (although still showing much alpha-delta eutectoid in its microstructure), even with a tin content of 14%. The uncored matrix shows varying degrees of cold-work rising to upwards of 250 HV in the cutting edge, near which, not unsurprisingly, there are signs of fine cracking. In a private communication, Coghlan has confirmed that hardnesses such as this, and even those of the halberd blade's edges, overlap the lower ranges found on Iron Age iron artefacts of much later date.

The observations made throughout this work agree well with the accepted views on moulds. For instance, the use of open stone moulds, with perhaps a flat capstone to cover most of the open upper surface, for flat axes, is consonant with evidence of 'set' surface segregation of copper/cuprous oxide eutectic found in the Newbury and the Devizes axes. Whereas the segregated oxide had been removed from much of the affected (upper) surface by understandably increased patination on the Newbury axe, enough remained for the effect to be clear, whilst it remained very obvious in the Devizes flat axe. As all flat axes seen by the writer are symmetrical in section, the use of an open mould indicates a necessity for a later shaping operation. The parting lines so commonly seen on cast artefacts are supporting evidence for the use of symmetrical bivalve moulds, many of which are known in stone and bronze form. Wells Museum posseses a modern casting of a winged and looped palstave made in such a bronze bivalve mould now in the Wells Museum. Despite dressing, the parting line is still clearly to be seen, whilst the cutting edge is blunt, and obviously in need of a sharpening operation such as those previously suggested. Evidence of the 'dressing' of parting lines by transverse application of an abrasive surface has been noticed on several artefacts so that it might even be considered whether an untreated parting line may be prima facie evidence that the product was being treated as a 'waster' by its maker. Socketed objects, of which there are many types in addition to axes, imply the use of a removable core and it seems accepted that these would be broken out after use. However, a socketed gouge in the Yattendon Hoard, now displayed in Newbury Museum, has vestiges of what may be parting lines, thus hinting at a potentially re-usuable two-part core. This, however, is a single observation, needing much amplification if it is established.

A continuing problem is that of crucibles, since those reported seem to be of small size and of later date. Up to the present, the writer has seen no signs of discontinuities in the metals which might point to interrupted pouring from a succession of small crucibles.

Apart from systematic excavations, Bronze Age objects are found by chance, either as single items, such as an excellent flat axe turned up in Somerset by a bulldozer and noticed by the driver, or many together, as in the Yattendon Hoard. This consists of nearly 60 mainly Late Bronze Age artefacts such as socketed swords, spearheads, knives, gouges, and axes, but including a few earlier forms such as flat axes and a palstave, Coghlan considers that the damaged form of many of these items indicates a stock intended for remelting. It appears rather rare for moulds to be found with these hoards, so one may surmise that the hoards were hidden during 'sales campaigns' rather than at the 'factory'. The period of roughly 2500 to 4000 years which separates the present day from the Bronze Age is shorter than it looks. The fine bronze horses to be seen in Venice are attributed to Greece in about 400 BC, and complicated metal objects such as fine statues and double-skinned water boilers were buried in Herculaneum and Pompeii by the erruption of Vesuvius in AD 79. Well over a thousand years was to elapse before technically comparable metal products were made in Western Europe during the Renaissance, by artists such as Donatello and Cellini.

Scientific metallurgy is little over 100 years old, and within the writer's working life, he saw such working methods as observing the 'set' on the open surface of a spoon sample of copper to check its progress during 'poling' to the 'tough pitch' stage. This, and many other empirical methods are probably still in use. The prehistoric craftsmen produced copper almost equal to the best modern standard, and often worked his metals near to the limit of their capabilities. He also showed command of his material, for instance, in the shape and related hardnesses in the alloyed halberd blade, whilst choosing ductile pure copper for the rivets. Can it be doubted that he was as skilled, in his time, as any craftsman is today?

Notes and News

PROFESSOR F. PIŠEK

In March 1970, Professor František Pišek died at Brno a few days before his 83rd birthday. One of the most distinguished Czechoslovakian metallurgists, he was specially outstanding in the field of foundry technology. He was deeply interested in the history of metallurgy, as evidenced by the republication of the famous series of mid-16th century founder's notes by Křička (Matthew of Bohemia) under his editorship. Pišek, who had been rector and dean of the Technical High School at Brno, received many honours, among them Honorary Membership of The Iron and Steel Institute. He was a member of the Republic of Czechoslovakia and of the Czechoslovak Academy. He had honorary doctorates from Friburg, Brno, and Košice, with medals of honour from the U.S.S.R. and from France. He was one of the very few men who had twice been President of the International Committee of Foundry Technical Associations.

ERRATA

In the last issue, Vol. 4, No. 1., 1970, the title of Mr Davies-Shiel's article on page 28 should have read:- Excavation at Stony Hazel, High Furness, Lake District, 1968-1969; an interim report. The mistake was repeated in the contents list on page 1.

The following footnote was omitted from the paper by Rao, Mukherjee, and Lahiri (Vol. 4, No. 1, pp. 12-17).

> Mr K.N.P. Rao is the Technical Adviser to the General Manager, Tata Iron & Steel Co. Limited and Dr J. K. Mukherjee and Dr A. K. Lahiri are Scientists at the National Metallurgical Laboratory. The facilities for carrying out the tests were provided at the National Metallurgical Laboratory, which the authors would like to acknowledge.

TIN IN THE HISTORY OF SCIENCE, TECHNOLOGY, AND ART

Prague, September, 1969

It was a strange coincidence that, while the Historical Metallurgy Group was holding its Annual Conference on the Tin Industry in Cornwall, the Czechoslovaks were holding an international meeting on the same subject in Bohemia. This was organized by the National Technical Museum and the Czechoslovak Society for the History of Science and Techniques (part of the Czechoslovak Academy of Science) and was held in Prague from 23 to 26 September.

The programme included a number of papers and excursions to the famous mining areas near Mariánské Lázně, Kynžvart, Horni Slavkov, and Karlový Vary. The main themes under discussion included tin ore deposits, development of mining and ore dressing, history of tin smelting, and the importance of tin in science, technology, and art. So far, one paper has been published by the National Technical Museum: this is by Jiří Majer and is entitled, 'Těžba cínu ve Slavkovském lese v 16. stoleti'. The author has prepared a German summary, and an abridged translation of this has been prepared for us which is printed below.

The tin deposits of Bohemia adjoin those of Saxony and together make up one of the once important tin mining areas of the world. In Bohemia, tin mining reached its zenith in the 16th century and the workings of this period seem to have obliterated the early workings, as has happened in so many mining areas. Majer's report runs to 216 pages in large octavo format and so is rather larger than the average conference paper. We look forward to further contributions on this subject.

Tin mining in the Kaiserwald during the 16th century

JIŘÍ MAJER

The three main tin ore deposits worked in Europe during medieval times were in England in Cornwall and Devon, in Saxony in the Ore mountains, and in Bohemia in the area of the Kaiserwald, which in the 16th century became one of the main centres of tin production.

HISTORICAL SECTION

The first phase falls into prehistoric times when alluvial deposits were exploited in north Bohemia. Intensified mining of primary deposits began in the 13th century when Bohemian tin competed with that of Cornwall on the European market. The two main areas at this time were Graupen in the Ore Mountains and Schönfeld in the Kaiserwald. At the beginning of 16th century, however, a massive deposit was discovered in Schlaggenwald and the surrounding area known as the 'Huber-stock'. Mining developed rapidly under the landowning aristocracy of Pflug von Rabenstein, to which both Schönfeld and Schlaggenwald belonged. They gave their support to the working of the mines, and in 1507 introduced the first laws for silver mining and in 1509 for tin mining. These laid the foundation for the so-called Annaberger Law appearing later in the same year, suitably combining older local law traditions. Between the years 1517 and 1541 a series of new clauses were added and served as models for similar mining rights.

The main period of the development of tin mining in Kaiserwald begins in about 1516 with the discovery of deposits containing 8-10% of tin. Mining was extended from the area of Schlaggenwald and Schönfeld, to Sangerberg, Lauterbach, Schönfickt, Königswart, Glatzen, and to the slopes near Marienbad. Mining grew to such an extent that by 1525 the increase in output led to coins being minted for a short time at the Pfluger mint using local silver deposits. The population increased to 8000 at Schlaggenwald in the thirties of the 16th centry. Tin in the Kaiserwald soon became the object of trade transactions attracting the large banks such as those of Fugger, Welser, Schnoden etc., engaged in the metal trade of the whole of Europe. After this promising beginning and activity for 30 years, the outbreak of war after 1547 (Schmalkalden Krieg) interrupted mining; this area was anti-Habsburg. The conquest by the Habsburgs led to property being confiscated, and trade relations with traditional export centres (i.e. Antwerp, Nürnberg, Augsburg, and Leipzig) were disrupted, causing a rapid decline in mining. In 1547, Schlaggenwald and Schönfeld restarted operations and on 1 January 1548 a new mining law was enacted. A supreme mines inspectorate was set up in Schlaggenwald for the whole Kaiserwald area. Between 1550 and 1553 it tried to establish a monopoly over the whole of Bohemian tin; the main buyer was an Augsburg merchant and the profit to the royal purse for this short period amounted to 173, 690 guilders. A royal monopoly had been set up originally for a period of 20 years which was however lifted because of the boycott of the mine owners and competition from Saxony. The high output achieved in the years 1530-40 of more than 500 tons per annum was never again achieved. By now all open-cast mining deposits had been exhausted, and deep mining was expensive and the tin content lower. A continued rise in prices from 1560 onwards contributed towards a decline. A crisis arose through the great fire of the town of Schlaggenwald in 1567, and in 1568 the subsidence occurred of two large mines, the clearing of which caused a considerable amount of expense. A suggestion by royal officials of a renewal of a monopoly on a wider scale in conjunction with Saxony to aid the depleted fortunes of the mine owners met with no approval. Decline in production continued in the following decades in spite of the efforts of the authorities, who offered tax reduction and credit. The reason for the decline lay not only in higher running costs but also in the decline of the demand by foreign markets connected with the wars in France, the fight for independence of the Netherlands, and the increasing production of Cornish tin. In the 1590's the annual tin production had fallen to 250 tons in the Kaiserwald and supported only 5000 persons.

The final decline was due to complicated economic conditions and political troubles in Bohemia at the beginning of 17th century before the outbreak of the 30 years' war. Annual production in Schlaggenwald fell to 100 tons, and at Lauterbach and Schönfeld production ceased completely. Efforts by the mining committee to reopen the mines in 18th century were unsuccessful.

In the 19th and 20th century, deposits of wolfram and uranium and other metals in this area revived mining to some extent, but the important deposits worked in the 16th century had been exhausted.

TECHNICAL SECTION

Position of the deposit in Kaiserwald

Whilst mining in this area shows similar general characteristics to other European mining areas, it has its own individual character. The Kaiserwald ore deposits are a continuation of the Bohemian-Saxony Ore Mountains. They are embedded in granite formations and occur in two zones which penetrate the gneiss- and slate formations vertically to the so-called Ore Mountain fault. The east zone is characterized by the historical mining sites in an approximate line of Graupen, Zinnwald, Altenberg, and Dippoldiswald; the west zone follows the line Sangerberg, Lauterbach, Schönfeld, Schlaggenwald, Bergstadt Platten, Eibenstock, Geyer, and Ehrenfriedersdorf. Apart from these are some isolated deposits on the Saxon side near Marienbad and Seiffen, and in Bohemia near Neustadt in the Tafelfichte.

In the area of Kaiserwald the deposit occurs in two formations: in old lodes and in quartz veins containing cassiterite. The main lodes are between Schlaggenwald and Schönfeld; they were discovered at the beginning of 16th century and were called Huber-, Klinger- and Hohensteiner-stock. Of the veins worked during this period, two series were significant, especially those dipping at 25-55° in a SW to NE direction. The most exploited veins in 16th century were Gelnauer, Marien, Anton, and Kluft-Gang. Other areas exploited in the Kaiserwald were the rich contact zone of the Greisen granite and the zone of ore veins near Lauterbach, the Greisen-lode (Greis means old) near Sangerberg and smaller deposits in the area of Hohen Glatzen and Konigsstein Gegenstadt. The ore in the open-cast areas contained about 8.5-10% tin; at a depth of about 150 m the tin content was only 0.5%, which agrees with the quality of the ores in the rest of the Bohemian and Saxon deposits.

Washing of ore

Washing of alluvial deposits had already begun in prehistoric times and was particularly active in 12th and 13th century; it continued in some parts up to the 15th and 16th century side by side with underground mining. The most important deposits were near streams, i.e. in the Schlaggenwald, Rota, Auschaer, Lauterbach, Tepl, Eger, and other streams, and in some areas traces of old activities can be found. In the 12th-16th centuries the alluvial deposits covered a total area of about 150 hectares in the Kaiserwald.

The method of washing was simple: the material was washed in streams, artificial leats often several hundred metres long, or in buddles of different types and in sieves. The technique of washing tinsand was no different from that of other ores. The most important tool, the seven-toothed fork, was incorporated into the arms of the mining towns of Schlaggenwald, Schönfeld, and Lauterbach. The leasing of alluvial tin setts was operated by the local mining councils and their measurement was 42 × 42 fathoms. The total amount of tin produced from these alluvial deposits in the area of Kaiserwald was about 3,000-3,500 tons.

Mining laws

The most important production in the Kaiserwald in the 16th century was by deep mining. Exact rules and mining regulations were laid down and kept up to date. The regulations varied with the character of the deposit. In Schlaggenwald generally two types of deposits were leased out: a simple sett of one weir (7 × 7 fathoms) or one of several weirs (7 × 14, 7 × 21 etc.) this was modified according to the character of the gneiss deposit; there were divergencies in measurements and shape; some were triangular, rhomboidal, or trapezoidal.

The ore was mined by a system of shafts, galleries, and tunnels. The opening of the mine was usually 2 × 3 fathoms in section or smaller ($1\frac{1}{4} \times \frac{3}{4}$ fathoms). The main and winding shafts were larger, but galleries and transverse tunnels had only a minimal section, mostly about 160 × 50 cm.

Mining characteristics

The opening of the ore deposits in the Kaiserwald was haphazard and no unified system of winding shafts existed; hundreds of galleries and tunnels were laid out to get to the ore. The more important deposits were small (the maximum diameter of the conical-shaped Huber deposit was about 192 m) and after the first onslaught a more efficient system had to be employed. Roof supports and a shaft for de-watering the mine were installed and by the end of 16th century the deposit was worked to a depth of 200 m in Schlaggenwald and Schönfeld, which was quite remarkable in view of the flat character of that terrain. In other areas a depth of no more than 40-50 m was reached.

Gallery workings

Apart from shafts, galleries and tunnels were driven into the mine and the oldest of these is dated to 1495. When one deposit was worked out, further galleries and tunnels were built; among the most important were the Schnoden (1535) and the Kaspar-Pflug (1539). The latter reached a length of 60 fathoms and by the beginning of the 17th century it was extended to give a total length of 3038 fathoms, connecting most of the old tunnels; up to 1604, 24 shafts had been sunk into it. Its installations were the largest and best planned in Europe.

Mining methods

The ore was mined with iron tools, and by fire-setting. In the Greisen deposits stoping was usual. In the Huber deposit they reached a height of 15-20 m; the average height was 5-7 m and length 12-15 m, and between the stopes timber frames were erected 3-5 fathoms apart. As many as 4 to 5 stopes could be vertically above each other in different levels, which often caused collapse, as in Altenberg. The area of subsidence in the Huber deposit extended for about 6.5 hectares.

Good results were achieved even with such simple mining techniques. The weekly output of broken ore was on the average 1 m^3, with an average daily output of ca. 6 quintals. In the Pflug gallery the advance in 3 months was about 9 fathoms. For the period 1500-1620, roughly a million tons of rock were removed. A relatively small number of workers were employed and the average age reached by a worker was 40.

Winding machines, pits, ventilation

Winding was by means of horse gins using one rope. From the second half of the 16th century two ropes were used, driven by two to four horse gins hauling the ore from a depth of about 160 m. The capacity was about 13 tons per shift. For horizontal transport, sledges and barrows were used. The ventilation technique was conservative, the main emphasis being on natural draught, for which old shafts were used.

Pumping and de-watering

Pumping and de-watering were mainly with buckets and paternoster pumps worked by waterwheel. In 1551 the newly invented piston pump worked with rods was used.

Water supply

A sufficient amount of water was essential for working the stamping mills, pumps, ore-washing etc. Natural water power from streams was insufficient, and at the end of the 14th century the first artificial leat was built, drawing water from the bogs in the area of Konigswart more than 20 km from Schlaggenwald. This was widened and lengthened in 1499 and between 1531 and 1536 was 24 km long, the largest at that time. Along it 35 bridges and 13 dams were erected. Several other leats were built with branches leading to the various mines, and strict laws were instituted for the use of water.

To supplement this artificial network, nine main ponds were excavated, covering an area of 720 hectares and containing over 6.3 million hl of water, which served as reservoirs during dry periods.

Use of forests for mining

The use of wood from the forests was free at the beginning of the 16th century; however, this was soon used up and wood had to be transported from areas such as Petschau. By the middle of the 16th century strict forestry laws were introduced, including the replanting of trees. In 1580, when production of tin was already on the decline, nearly 76,000 cubic metres of wood were consumed annually in the areas of Schlaggenwald and Schönfeld alone. In the years of 1516-1620 a rough estimate of the area of wood consumed in the Kaiserwald would amount to at least 14,000 hectares.

Preparation of ores

Tin production involved one of the most difficult technological processes of the 16th century. Preparation of the ore alone involved four phases:

(1) sorting and crushing with the hammer
(2) roasting in open hearths
(3) reducing ore to fine size in ore- or stamp mills
(4) washing

Crushing of ore by mechanical means developed in the 16th century. During the 15th century handmills were used, but later stampmills worked by water power were introduced. From 1525 a wet process was employed to prevent loss of metal through dispersion as dust. The loss of metal, however, was still 20-25%. Several improvements were introduced during the course of the 16th century. Washing in wood and canvas troughs achieved remarkable homogeneity of the ore fines, which were then dried before smelting. 91 installations were preparing the ore in Schlaggenwald and Schönfeld, and there were 34 in other areas. The stamping mills had 3-4 hammers and were worked by 1-3 waterwheels. A mill with 3 crushers crushed 450-470 tons of ore a year. Four crushers produced 650-1000 tons of fine ore. The installations were of three sizes: (1) 2-7, (2) 8-11, and (3) 12-29 people. Altogether Schlaggenwald and Schönfield had 30 stamping mills.

Smelting of ores

Smelting involved several operations. Ores were roasted in dome-shaped reverberatory furnaces, then washed, ground in the ore mill, and washed again. Smelting was carried out in square shaft furnaces 2.5-2.7 m high with chambers built over them for the deposition of flue dust. The molten tin was then purified by 'flossen'. The good tin was cast into grids, the poorer tin cast into bun-shaped ingots. It was then marked with a stamp and packed in 5-10 cwt barrels.

Charcoal was used for smelting, 44-55 kg charcoal to 100 kg of ore. Loss during smelting was considerable; even at the beginning of the 19th century it amounted to 50% of the tin. 32 smelters were active in Schlaggenwald and Schönfield; the proportion of smelters to preparatory installation was in the ratio of 1 : 3.

Economics

In the period 1500-1620 the production of tin was about 35,000 tons. The annual output between 1520 and 1540 was 400 tons. At the end of the century before the outbreak of the Thirty Years War it was 75 tons. The tin production in the Kaiserwald during the 16th century was 62% of the whole Bohemian tin production, the rest being produced in the Ore Mountains. After 1620 the English production was higher.

Before the 16th century the tin was mostly exported to Bruges. During the 16th century it was mainly exported to Nurnberg, Augsburg, Leipzig, and Antwerp, from where it was distributed over the whole of Europe. Later, the export market declined, partly because of political unrest in Western Europe but mainly because of the increase in price due to the so-called 'price revolution'. An important part of the tin production was used in workshops of which there was one in every Bohemian town. A certain amount was regularly sent to the Army in Austria and East Hungary, where it was used for making bronze cannon. Tin became a metal of fashion and was used for tableware, for decorative and religious purposes, and especially in printing, mirror making, glazing of cooking pots, tin plate, enamelling, and for colour production.

The decline of the industry was associated with the increase in furnace building costs and the decline in the quality of the ore. There were also considerable increases in the cost of charcoal, transport, and wages. While the profit at the beginning of the 16th century when they were working ore containing 8-10% tin could be 300-400%, by the end of the century with the ore grade at only 0.5% the profit had declined to about 12%.

A pre-Roman iron-smelting site at Levisham, North Yorkshire

As part of a large-scale investigation of early remains on Levisham Moor (NGR SE 830 922), J. G. Rutter and F. C. Rimmington have found the remains of an iron-smelting furnace tentatively dated to AD 50-70. This furnace is particularly interesting as it resembles in many respects that found at Engsbachtal in the Siegerland[1], West Germany, dated to a similar period. These furnaces have similar features to the medieval furnace found at High Bishopley in Co. Durham[2]. They therefore seem to constitute a type, which might be termed the 'Domed' furnace.

The furnace at Levisham is 1 to 1.5 m outside diameter and its present height is about 0.5 m. The inside consists of a bowl-shaped smelting zone 30 cm dia. × 40 cm high, narrowing to 20 cm dia. at the top. The 'bowl' communicates with the outside by means of a 40 cm long horizontal passage through which the bellows were inserted, if one assumes that it was bellows-blown. It would appear that slag was not tapped from this furnace, as no obvious tap-slag was found on the site; on the other hand there were furnace bottoms of plano-convex type, and slag prills as were found at West Brandon in Co. Durham[3]. All these features are characteristic of the pre-Roman Iron Age. Adjoining the blowing aperture was a long pit or working space which, like the bottom of the furnace, was about 30 cm below the original ground level.

The dome was made of a conglomerate of clay, slag, and stones and was hard-burnt. It appeared to have been built beside and perhaps over the remains of earlier furnaces of similar pattern. The furnace was centrally situated inside a round hut of the usual Iron Age type, consisting of a circle of postholes of about 6 m diameter surrounded by a ditch. This ditch had an opening in its south-east side; the furnace opening was on the north-east side.

The site lies several miles south of the main outcrops of bedded ore, but the remains of ore found on the site seem to be nodular in origin and could have been brought from less than a mile away.

A large Iron Age rectangular enclosure lies near the furnace, which was probably supplying the needs of the settlement within. A small quantity of late Early Iron Age pottery was found around the furnace but no definite Romano-British pottery. Some of the latter was found on adjacent excavated sites.

(We are indebted to J. G. Rutter of the Scarborough Museum and to R. H. Hayes for the above information. Ed.)

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Analyses of copper ores

H. H. COGHLAN AND R. F. TYLECOTE

In 1963 the Royal Anthropological Institute published an occasional paper on 'Ores and Metals' which gave the results of one of the most comprehensive analytical programmes yet attempted on the copper ores of the British Isles. The following results, which arise from work kindly carried out by the Morgan Crucible Co. Ltd., supplement the R.A.I. results. The ores were analysed with a large Littrow spectrograph, using total combustion and a DC arc. Forty-six elements were sought; of these twenty-three were present in amounts greater than the limits of detection.

These results will allow us to compare analysed artifacts with possible ore sources when one takes into account the losses on smelting. Some points of interest emerge such as the presence of small amounts of tin in some of the Cornish ores, part of which would undoubtedly be taken up in the copper, although some would go into the slag as we know from that made at Hayle. Another element present in significant amounts is Zn; although this element is volatile like As, quite a lot of it will be recovered and one can expect to find some Zn in the coppers made from Zn-containing ores. None of the ores analysed here will give Zn contents exceeding about 5% in the final metal.

Acknowledgement

We are extremely grateful to Mr J. C. H. Stephens and the Morgan Crucible Co. Ltd. for these results.

Composition of Copper, Ores %

No.	Type and Provenance	Cu	Sn	Pb	Ag	As	Sb	Bi	Zn	Ni	Co	Fe	Mn	V	Ti	Si	Al	In[4]	Ca	Mg	B	P	Ge	Mo
9407	Copper pyrites (Schull. Co. Cork)	>30	nd	0.002	0.001	nd	0.005	nd	nd	nd	nd	~30	nd	nd	nd	0.003	0.01	0.002	nd	0.001	nd	nd	—	—
8093	Bornite (Levant, Cornwall)	>30	0.1	0.002	0.002	0.05	0.01	0.03	nd	nd	nd	>20	0.02	nd	nd	0.2	0.2	0.05	nd	0.01	nd	nd	—	—
8096	Olivenite (Wheal Unity Gwennap, Cornwall)	>30	nd	0.005	nd	~20	nd	nd	0.01	nd	nd	0.1	0.001	nd	nd	0.1	0.02	nd	nd	0.002	nd	1-2	—	—
8103	Chalcocite (Levant, Cornwall)	>30	~5	0.01	0.01	0.3	0.005	0.003	nd	0.1[3]	0.1[3]	>20[6]	0.001	nd	0.005	0.5	0.3	0.001	nd	0.02	0.05	nd	—	—
8105	Tetrahedrite (Loch Tay)	>30	0.005	0.003	~1	~5	~20	0.001	~3	0.02[3]	nd	~3	0.01	nd	nd	0.4	0.01	nd	0.5	0.03	nd	nd	—	—
8108	Native Cu[5] (Levant, Cornwall)	M	nd	0.002-0.004	0.01	nd	nd	nd	nd	nd	nd	0.03	0.002	nd	nd	0.05	0.03	nd	0.01	0.03	nd	nd[2]	—	—
8424	Tetrahedrite (St. Blazey, Cornwall)	>30	0.01	~0.3	~2[1]	0.5	~20	nd	~3	nd	nd	~3	nd	<0.005	nd	0.03	0.001	0.001	nd	0.001	nd	nd	—	—
8139	Tetrahedrite (Allihies, Co. Cork)	>30	nd	0.002	0.02	~1	~20	0.02	~1	0.01	—	~5	nd	nd	0.01	0.03	0.02	nd	nd	0.002	—	nd	nd	nd
8429	Tetrahedrite (Ballycummisk Co. Cork)	>30	nd	0.002	0.03	0.5	~20[7]	0.01	~1	0.01	—	~5	0.05	nd	0.1	~6	0.4	nd	0.2	0.3	—	nd	nd	0.1
8404	Tennantite (West Wheal Jewel, Cornwall)	>30	0.5	0.1	0.03	~5	<0.01	0.005	nd	0.02	—	~2	0.05	nd	0.01	~5	0.02	0.005	nd	0.001	—	nd	0.01[4]	0.1
8405	Tennantite (Wheal Jewel, Cornwall)	>30	nd	0.002	0.005	~7	<0.01	nd	nd	nd	—	~5	nd	nd	0.01	0.02	0.001	nd	nd	0.0001	—	nd	nd	0.002
8406	Tetrahedrite (Lanreath, Cornwall)	>30	nd	0.05	~2[8]	0.5	~20	0.003	~1	0.01	—	~3	nd	nd	0.01	0.02	0.001	nd	nd	0.001	—	nd	nd	nd
8091	Tetrahedrite (Grinnis, Par, Cornwall)	>30	0.03	0.03	~2[1]	0.5	>20	0.001	~3	nd	nd	~5	nd	<0.005	nd	0.1	0.02	0.001	nd	0.001	nd	nd	—	—
8425	Tetrahedrite (Cornwall)	>30	nd	0.01	~2[1]	~2	>20	0.03	~3	nd	nd	~3	nd	<0.005	nd	0.02	0.003	nd	nd	0.001	nd	nd	—	—
Limit of detection		—	0.005	0.002	0.0005	0.05	0.005	0.0005	0.01	0.01	0.01	0.001	0.0001	0.002	0.005	0.002	0.001	0.0005	0.01	0.0001	0.01	0.3	0.005	0.002

Notes

M Major constituent.

1 The Ag content may be a little higher than 2%.

2 Limit of detection of P in Cu is 0.1%.

3 These Ni and Co figures are doubtful; probably introduced by sampling.

4 No standards available; figures estimated.

5 In the native Cu, the Si, Al, Ca and Mg (and possibly Fe and Mn also) were most likely in the surface and not in the massive metal; the surface was not thoroughly cleaned.

6 The high iron content of the chalcocite prompts the question: 'Is it chalcocite?'

7 Although ~20%, it was somewhat less than in Sample 8139.

8 Uncertain about this figure; it could be higher.

nd = Not detected.

Also sought but not found, with approximate limits of detection (%):-

Li	0.1	Ga	0.01	Zr	0.01
Na	0.1	Tl	0.01?	Hf	0.01
K	2	Ge*	0.01	Th	0.1
Be	0.01	Cd	0.01	Nb	0.1?
Sr	0.1?	Hg	0.1?	Ta	0.1?
Ba	0.1	Au	0.01?	Cr	0.02
W	0.05	Pt	0.01	Mo*	0.02
Sc	0.1	Y	0.1	La	0.1
Ce	1				

* In some cases these elements have been detected using techniques giving lower limits of detection.

'Vitrified products'- a comment

L. BIEK

Evans and Tylecote[1] have dealt with some of the problems which face an archaeologist and his metallurgist friend in answering the common question: 'When is a slag not a slag ?'. The purpose of this brief comment is to draw attention to some analyses which suggest that the previous authors' conclusions might be refined and amplified.

General

Many of the remarks below are based on evidence obtained during work on material from the area of what has become Chew Valley Lake, in the Mendips south of Bristol[2]. It is hoped to publish metallurgical and ancillary results in extenso in a later issue of the Bulletin

It would seem that there is a whole range of material derived from vegetable sources that under suitable conditions can give rise to 'slags'. Within this range the changes in composition may be virtually continuous in respect of the alkali and alkaline earth metals, so that firm distinctions of sources become difficult. An additional factor which introduces another dimension of compositional changes is the nature of the fluxed matrix. Thus the ash from wheat grains will by itself have the right composition to vitrify[3]. A fierce fire involving the whole wheat plant, stored in bulk on a sandy clay floor, could at hot spots produce 'slags' of similar composition except for the higher alumina content[2], but on a sandy floor this could be much reduced.

Glasses, in turn, can have a wide range of compositions, in some cases approaching very closely to such accidental fluxes which, after all, show a close family resemblance to the intentional variety. The term glass 'slag' may be misleading by analogy with metallurgical processes, suggesting as it does a waste product regularly obtained during smelting, whereas glass-making involves melting only, and leaves no waste product except substandard material which can be returned to the next charge. 'Pot skimmings' might be vesicular enough to pass as 'slag'.

Finally there is a class of mineral material ranging over compositions that can be self-fluxing under suitable conditions and at the right temperatures. Certain sideritic ores provide typical examples at one end of this range. Even here, the resulting 'slags' may sometimes be of no metallurgical significance, depending on intentions and state of knowledge attributable to the people that produced them. Certainly at the other end of the range, 'vitrified forts' and similar material produced accidentally constitute a further class of product that might mislead metallurgists. If various permutations of the possibilities are considered, it is clear that end-products with similar compositions may be arrived at by several different routes.

In all cases, of course, relatively high temperatures are indicated, and to that extent any of this material may be found useful evidence. By the same token, although some of the material such as charcoal-ash slag may strictly have no direct metallurgical significance, it may nevertheless have been produced (like the fuel slag on the outside of a crucible) during a smelting operation. On the other hand, fluxed half-channels found in debris at a Saxon glass-melting furnace[4] were reminiscent of small broken tuyeres, although they were clearly the result of 'wattle' ash fluxing the surfaces of 'daub' which enclosed it.

Specific

With regard to the material from Hawk's Hill which was described as cow dung on the basis of its analysis, some caution would seem to be indicated, since it is probable that neither the high silica nor the high phosphate is definitive in this respect. Similarly, ash from seaweed could lead to vitrified products similar to those from peat ash, both being rich in sulphur. Some comparative figures are given in Table I, but it is hoped that further investigation of a number of archaeological specimens collected at the Ancient Monuments Laboratory from various contexts may more clearly define the general position. It should be stressed, however, that factors other than composition, such as appearance, density, and other physical properties, should be fully used in conjunction with analytical data in interpretation.

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TABLE I Compositions of some vitrified materials and fluxing agents, wt–%

	Cow dung, England[1]	Islamic glass Egypt[3]	Vegetable ash slag[2] CP 413	Cereal and clay slag[2] (calculated)	16-17th century glass England (Kirdford)[3]	Vegetable ash slag[2] CP 309	Hawk's Hill[1]	Vegetable ash slag[2] CP TH3	Sand, March 1954 Egypt[3]	Vegetable ash slag[2] CP Type C	Peat ash[1]	Kelp from seaweed[3]
SiO_2	56.3	49.4	59.11	59	64.6	62.0	>80	76.8	72.69	72.08	3–30	1.6
Fe_2O_3	17.6	8.6	1.72	5	0.67	1.75	v. little	3.7	5.6	6.01	10–20	—
Al_2O_3		14.5	17.71	20	1.24	15.45	v. little	5.3	8.18	7.2	0–5	0.1
MnO		1.3	1.48	—	0.9	0.74	—	<0.1	0.09	—	0–1	—
CaO	17.6	18.7	6.1	1.2	20.8	4.40	4.2	8.7	4.86	2.6	24–30	7
MgO	0.35	1.4	2.88	0.5	2.62	1.78	0.55	2.16	2.44	1.33	1–7	0.3
K_2O	1.54	3.5	3.0	5.3	4.77	4.7	7.2	—	—	—	0–1	13*
Na_2O	1.68	2.4	0.6	0.8	0.43	0.92	1.65	—	—	—	0–2	18*
P_2O_5	2.45	1.2	2.4	6.5	1.7	3.7	5.06	—	0.12	0.46	0–3	8
SO_3	—	—	<0.05	0.6	0.24	<0.05	—	—	0.06	<0.01	5–10	6
Cl	—	—	—	—	—	—	—	—	—	—	—	25

Notes:- — = not determined
* includes other compounds of Na and K

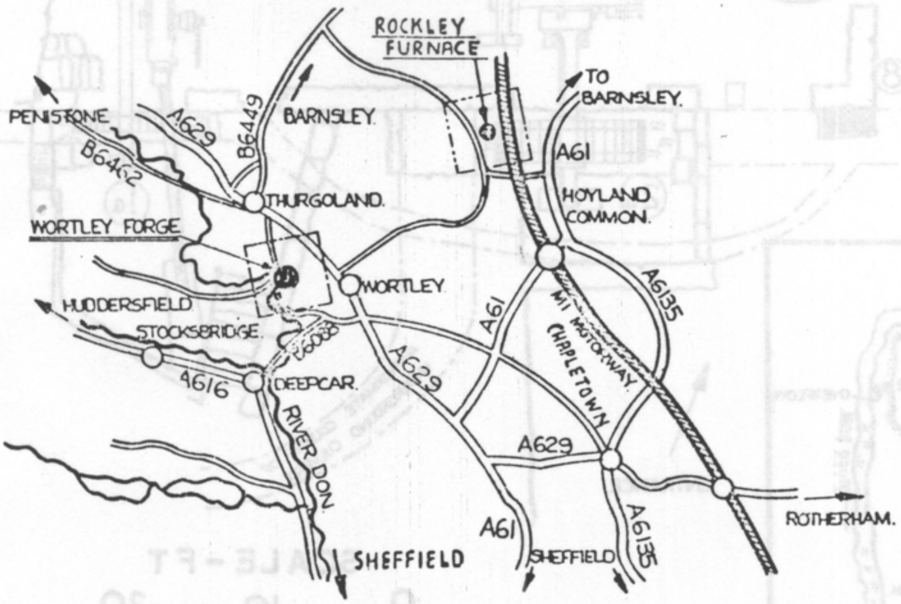
Top Forge, Wortley

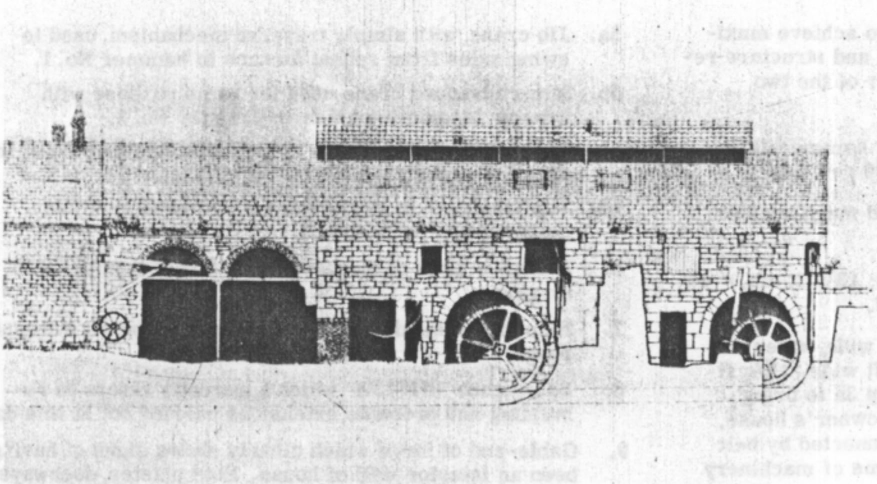
The remaining part of a South Yorkshire ironworks is scheduled as an Ancient Monument and is in the care of the Sheffield Trades Historical Society. This forge operated over a period of 250-300 years, finally ceasing work in 1912.

K. C. Barraclough has prepared the following notes for the benefit of visitors and has kindly allowed us to reproduce them here.

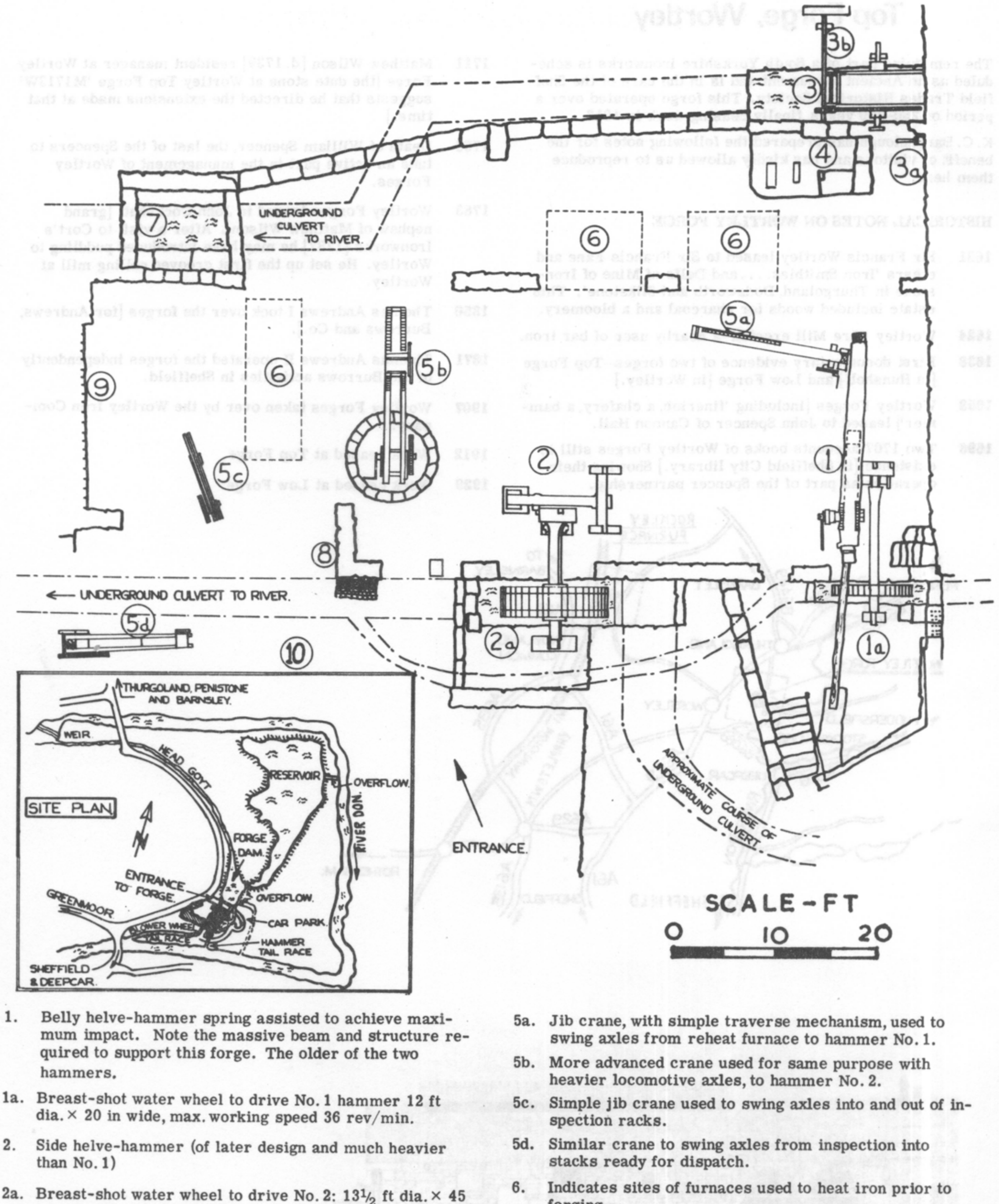
HISTORICAL NOTES ON WORTLEY FORGE

1621	Sir Francis Wortley leased to Sir Francis Fane and others 'Iron Smithies.... and Delfs of Mine of Ironstone in Thurgoland, Dodsworth and Silkstone'. This estate included woods for charcoal and a bloomery.
1624	Wortley Wire Mill erected—a nearby user of bar iron.
1638	First documentary evidence of two forges—Top Forge [in Hunshelf] and Low Forge [in Wortley.]
1658	Wortley Forges [including 'fineries, a chafery, a hammer'] leased to John Spencer of Cannon Hall.
1696	Two 1707 accounts books of Wortley Forges still in existence [in Sheffield City library.] Showing their operation as part of the Spencer partnership.
1711	Matthew Wilson [d. 1739] resident manager at Wortley Forge [the date stone at Wortley Top Forge 'M1713W' suggests that he directed the extensions made at that time.]
1756	Death of William Spencer, the last of the Spencers to take an active part in the management of Wortley Forges.
1783	Wortley Forges leased to John Cockshutt [grand nephew of Matthew Wilson]. After a visit to Cort's Ironworks [1787] he may have introduced puddling to Wortley. He set up the first grooved rolling mill at Wortley.
1850	Thomas Andrews I took over the forges [for Andrews, Burrows and Co.].
1871	Thomas Andrews II operated the forges independently of the Burrows activities in Sheffield.
1907	Wortley Forges taken over by the Wortley Iron Company.
1912	Work ceased at Top Forge.
1929	Work ceased at Low Forge.





Top Forge, Wortley—East Elevation.



1. Belly helve-hammer spring assisted to achieve maximum impact. Note the massive beam and structure required to support this forge. The older of the two hammers.

1a. Breast-shot water wheel to drive No. 1 hammer 12 ft dia. × 20 in wide, max. working speed 36 rev/min.

2. Side helve-hammer (of later design and much heavier than No. 1)

2a. Breast-shot water wheel to drive No. 2: 13½ ft dia. × 45 in wide. Working speed 25-30 rev/min.

3. Pitchback water wheel 9 ft dia. × 44 in wide, water supply from pentrough dated 1850 3½ ft wide × 9½ ft long × 5½ ft deep used to operate pump 3a to bring spring water from 200 yd upstream to owner's house. Back and gear wheel, 3b drove shaft connected by belt drive to line-shaft to drive various items of machinery.

4. Stone bed-plate for two horizontal blowers used to supply draught for earlier furnaces.

5a. Jib crane, with simple traverse mechanism, used to swing axles from reheat furnace to hammer No. 1.

5b. More advanced crane used for same purpose with heavier locomotive axles, to hammer No. 2.

5c. Simple jib crane used to swing axles into and out of inspection racks.

5d. Similar crane to swing axles from inspection into stacks ready for dispatch.

6. Indicates sites of furnaces used to heat iron prior to forging.

7. Remains of small office or kitchen with small Yorkshire range.

8. Date-stone 'M1713W' which apparently refers to rebuilding and probable extensions carried out at this date.

9. Gable-end of forge which clearly shows signs of having been an interior wall of house. Note plaster, doorways and floor joists.

10. Yard area where axles were stacked ready for dispatch.

Report of the Annual General Meeting 1970

Held at 2.15 p.m. in the Council Room of The Iron and Steel Institute, London, on 15 April 1970.

Present:

K. C. Barraclough, C. R. Blick, J. W. Butler, D. W. Crossley, R. C. Dyer, B. Fullman, W. K. V. Gale, B. M. Hardman, L. B. Hunt, H. Moore, CBE, G. R. Morton, H. O'Neill, N. Swindells, E. G. West, and R. F. Tylecote, with the President, M. M. Hallett, in the Chair.

Apologies for absence were received from R. Doncaster, M. W. Flinn, J. Mowat, N. Mutton, D. M. Headworth, S. H. Russell, H. F. Cleere, and Sir Frederick Scopes.

Minutes of the last A.G.M. on 17 April 1969, which were published in the Bulletin, Vol. 3, No. 2, p. 68, were taken as read and, with the addition of E. E. White's name to the list of those present, were signed as a correct record.

Matters arising

No matters were brought up.

Chairman's Report

Keith Gale gave a brief account of his management of the Group's affairs during the year. This was his second year of office and he pointed out that his main role had been that of general liaison between the Committee and outside bodies. He had been most active in the organization of the annual conference in Cornwall.

Secretary's Report

The Secretary pointed out that he combined his duties with those of Editor and that this would be his last year as Secretary, so that he hoped he would be in a position to devote more time to his editorial duties in future. As usual it had been possible to produce two issues of the Bulletin mainly through the good offices of The Iron and Steel Institute who did the production side of the work. He hoped that more members would play a greater part in the Bulletin, particularly by sending in notes, reviews, and abstracts of general metallurgical interest. The Bulletin was getting a good name abroad and as a result requests were being received from many foreign countries for membership, some offering exchange arrangements for similar publications.

The overall membership of the Group now stood at 334, showing an apparent decrease over the year; this was due to the new policy of the two Institutes who were now charging their members for the privilege of membership of the Group. It was felt that this figure was more realistic and it was clear that the overall membership was still rising at a healthy rate so that the losses would soon be made good. Roughly half the members were metallurgists, the other half being historians, economic historians, archaeologists and institutions.

As usual, an annual conference had been held, this time in Cornwall, and about 45 members were present. Discussion had taken place with the Institution of Metallurgists about the setting up of a reference collection of slides on historical matters. Representatives had attended meetings of the Industrial Archaeology sub-committee of the CBA and the Standing Committee on Local History.

Members had carried out several excavations during the year; amongst these should be mentioned the finery at Stony Hazel by M. Davies-Shiel and G. R. Morton, the blast furnace at Panningridge by David Crossley, and the excavation at Bardown and the smelting work at Horam carried out by Henry Cleere. The Secretary had been supervising an experimental smelting programme at Newcastle aided by the Carnegie Research Fund of the ISI and a report was now being drawn up giving the conclusions arising out of 32 smelts. During the year he had visited the site of Meroë in the Sudan to investigate the remains of iron smelting, now dated to about the first two centuries AD.

Treasurer's Report

The Treasurer presented his accounts, showing a credit balance of about £180. During the year he had been mainly concerned with the spending of money and it was apparent that he had been quite successful in this respect. The CBA subscription had been increased to £5 as from the current year. Grants had been made towards various excavations, the Ironbridge Gorge Trust, and to the Institution's Benevolent Fund. He reported that reprints of all Bulletins were now available and that an Index would shortly be published. For once he had been able to get the accounts out in time for them to be audited before the A.G.M. The Committee recommended that the annual subscription should now be 10/- for all members and that this would include postage of the Bulletins by surface mail to members at home and abroad. This was formally accepted by the meeting. Mr Butler drew attention to the fact that the accounts showed an element of subsidy of the non-metallurgical members by the metallurgical institutions. The meeting felt that this was in order, and the Treasurer pointed out that all members were being subsidized to some extent by the ISI.

Election of Officers and Committee

The names of the officers nominated by the Committee were put to the meeting one by one, Keith Gale proposing the President for a further term of office. All were duly proposed, seconded, and elected and it was felt that the principle of having the Chairman and the President retiring in alternate years was a good one and should be incorporated in the constitution. The President thanked the retiring Chairman for all the good work he had put in during his two years of office, particularly that in connection with the Cornish Conference which had been such a success.

It was announced that further nominations were required for the Committee as Professor M. W. Flinn had felt unable to accept the Committee's nomination. J. G. Rollins and J. W. Butler were proposed, seconded and duly elected. As a result of these elections the list of officers and committee is as follows:-

President	M. M. Hallett
Chairman	K. C. Barraclough
Hon. Sec.	D. W. Crossley
Hon. Editor and Asst. Hon. Sec.	R. F. Tylecote
Hon. Treasurer	C. R. Blick

Committee

Dr. N. Swindells
W. K. V. Gale
J. G. Rollins
J. W. Butler
B. H. Hardman
Professor H. O'Neill (representing The Institute of Metals)
H. F. Cleere } (representing The Iron and Steel Institute)
G. R. Morton }

Dr. W. Pumphrey was again elected as auditor

Honorary Membership of Dr. H. Moore, CBE

The President announced that Dr. H. Moore had been elected our first honorary member at the conference in Cornwall, and that it was a great pleasure now to have him present in person to receive his enrolment certificate. Dr. Moore had not only taken part in something like 80 years of metallurgical history but had also recorded it. He was a past president of The Institute of Metals and of The Institution of Metallurgists and had served in various capacities on many other bodies. He would be the Group's first honorary member. After receiving his certificate from the President attended by much acclamation, Dr. Moore gave a short speech of thanks during which he referred to his association with such famous men as Sorby and Stead.

Annual Conference

Professor O'Neill reported that arrangements were well advanced for the holding of the annual conference during the weekend 4-6th September at Swansea. Members would be accommodated at a University Hall of Residence on the campus. There would be talks on Friday evening and an all-day tour on the Saturday followed by discussions in the evening.

It was agreed to try to ensure that the authors of conference papers made their manuscripts available for preprinting a month before the conference.

Other business

Dr Dyer proposed a vote of thanks to the committee for their work during the year.

The meeting was formally closed and then immediately followed by K. C. Barraclough's chairman's address on 'Sheffield Steelmaking before Bessemer'. This was based on his recent research on the early history of the cementation and crucible melting processes.

Book Review

The Carbon-14 Dating of Iron, by Nikolaas J. van der Merwe. pp. xii plus 137. Pub. Chicago University Press, 1969. 69/4d.

The application of the carbon-14 dating method to establish the age of charcoal, bone, wood, and similar materials found in archaeological excavations has become a recognized technique over the past twenty years.

The present volume describes a rather fascinating extension of the technique to cover the dating of samples of cast iron and the higher-carbon steels. It can, obviously, only be applied to materials where the carbon used for the smelting operations was charcoal, as distinct from fossil fuel. It so happens that the use of coal (generally after conversion to coke) is a relatively late feature in the history of the metallurgy of iron; in this country coke only came into general use in the blast furnace towards the end of the eighteenth century, such a change from charcoal coming even later on the Continent and in America. Virtually the whole of the steel produced before 1860 was derived from wrought iron produced using charcoal in Sweden, the carbon for its conversion into steel in the remainder of Western Europe again coming from charcoal.

The technique described is therefore valid for most specimens of archaeological interest, as indeed is amply shown in the text by reference to the work done on a number of samples of known origin and of different date. It is also of particular interest in that a sample of recent but known date, submitted to such examination, can be categorized as to whether it was smelted using vegetable or fossil fuel (or possibly using a mixture of the two, which is known from existing records to have been the usage in certain cases).

The validity of the dating of charcoal-smelted iron is enhanced by the fact that charcoal does not store well as a fuel and is also produced, in general, from the thinner growths of the trees; what is actually being determined is the age of the wood from which the fuel was produced and this is only likely to antedate its metallurgical use by a few years at the outside. In addition, the leaching of later material into the sample to be submitted to analysis, a real source of error in general dating of this kind, is far less likely to occur within the sample of solid metal itself.

The book most admirably sets out this matter; it not only covers the principles of carbon-14 dating, the laboratory methods applied in this particular extension of the technique, and the results obtained, but also shows the possibility of applying the method to cover the dating of metallurgical slags from charcoal-smelting operations which, obviously, are far more likely to be found in an archaeological context than the metal itself. In addition it provides an admirable summary of the metallurgy of iron and its place in prehistory and history. Moreover, all this is well presented in a most readable form; the book will be of interest alike to the archaeologist, the economic historian, the analyst and the metallurgist.

K. C. Barraclough

Abstracts

General

The composition of metal artifacts; a guide to provenance? R. F. Tylecote. (Antiquity, 1970, 44, 19-25). This is an attempt to show the position reached by recent work on this subject. It reviews the main analytical techniques used and the results obtained in trying to relate artifacts made from the main metals of antiquity to possible areas of origin and the ores available in those areas.

Reduction of iron from its ore in the medieval bloomery. G. R. Morton and J. Wingrove. (Steel Times, 1970, April). Based upon a piece of partly reduced ore found in the smelting hearth of Crossley's bloomery excavation at Rockley Smithies. Comparison is made with what is known about the Catalan hearth process.

British Isles

Metal analyses and the Scottish Early Bronze Age. J. M. Coles. (Proc. Prehist. Soc., 1969, 35, 330-344). A presentation of the conclusions derived from the analytical work of Junghans, Sangmeister, and Schröder in Germany and Coghlan, Case, and Britton in this country on Scottish coppers and bronzes. The full results will appear in a future volume of the Proceedings of the Society of Antiquaries of Scotland.

A stone mould for axeheads from Doonour, Bantry, Co. Cork. M. J. O'Kelly. (J. Roy. Soc. Ant. Ireland, 1969, 99 (2), 117-124). A rectangular mould of O. R. S. ferruginous grit for flat axes and short dagger-shaped implements. It shows chisel or tracer marks made during the cutting of the matrices. It was clearly used as an open mould for rough castings which would need finishing by forging.

The Derwentcote Steel Furnace. J. K. Harrison. (Ind. Arch. Soc. for North East, Bull. 1969, 9, July, 12-18). It is good to see at last a report on this important relic which lies in the Derwent valley near Rowlands Gill, Co. Durham. It is probably the oldest cementation furnace in existence, but unlike those still remaining in the Sheffield area this is made of stone. Its dating is obscure, but Jars reported a cementation furnace near Newcastle in 1774 which is very similar to Derwentcote. It may even be the furnace seen by Kalmeter when he visited the area in 1719.

This paper gives a good description of the furnace and is well illustrated with drawings. The survey was made by a party of boys from Eston Grammar School. They found that the two outbuildings serving each hearth abutted on to the cone. Above the fire grates of each hearth are holes about 12 by 18 in which gave access to the chests above. There are many small flues to carry heat from the fire up into the chamber above the chests. This has an arched roof with flues to allow the gases into the upper part of the structure. At the ends of the chests, and level with their upper edges, are small square holes communicating with the outside through which the iron was loaded.

The conical chimney is elliptical in plan and about 3.6 m high. The whole furnace structure is in a pretty good state although the outbuildings are now derelict. Lord Gort, the owner, has generously presented the building for incorporation into the new regional open-air museum which is being established at Beamish Hall, and money has been made available for its removal and rebuilding.

The heyday of the muck bar. W. K. V. Gale. (Brit. Steel, 1969, Aug., 26-31). The contribution which wrought iron has made to the ferrous metals industry is reviewed.

A 19th century copper working: Tomnadashan, Lochtayside. J. W. Bainbridge. (Industrial Archaeology, 1970, 7, (1) 60-74). The history of a small unprofitable mine on the shore of Loch Tay in Perthshire (Grid ref. NN 682370). Chalcopyrite and grey ore (tetrahedrite) were mined between 1838 and 1862 and at one time smelted, as shown by the slag heap by the lochside. In 1853, 71 tons of ore went to Swansea for smelting. The grey ore contained 8-11.8% Cu, and the chalcopyrite 3.6-3.8% Cu and 30.3-37.9% S. The smelting furnaces and the sulphuric acid plant associated with them will be discussed in a later paper.

Siemens steelmaking at Swansea, 1969-88. H. O'Neill. (Met. Mat., 1969, 3, 312-316). The work of Sir William Siemens and the decline of the Landore Works are described.

The Ecton Copper mines. J. A. Robey. (Bull. Peak Dist. Mines Hist. Soc., 1969, 4, 145-155). Mostly about mining but there are references to the Ellastone smelt mill and the Esher brass works. The smelter produced 4.5 tons of metal in the 5 years beginning in 1660 from about 30 tons of copper ore.

The Ironbridge Gorge Museum Trust—Blist's Hill Industrial Open Air Museum. (Iron Steel, 1969, 42, June, 161-163). The museum contains the Coalport incline, the tar tunnel, remains of the ironworks, clay and tile works, and other features.

Europe

New copper-smelting sites in the Jochberg mining region near Kitzbühel, Tyrol. R. Pittioni. (Arch. Austriaca, 1969, 46, 57) [In Ger.]. The paper describes the remains of smelting sites found during the excavation for a pipeline. No satisfactory dating material was found but it is not impossible for these to belong to the Urn-field period.

Iron husbandry of early centuries in the district of the Styrian Erzberg and the outlook for future development. R. G. Walsel. (Nachr. Eisen-Bibliothek Georg-Fischer AG, 1969, Nov., 227-244) [In Ger.]. The economy of the Austrian steel industry is traced over the past 2000 years, and the changes which have taken place over the centuries are discussed from the point of view of future developments in the Austrian steel industry.

A medieval settlement with smithing places at Mutějovice, Western Bohemia. R. Pleiner. (Památky arch., 1969, 60, 533-571). [In Czech]. An excavation report on a site which yielded 723 smithing furnace bottoms, some tuyeres, and artifacts dated to the 11th-13th cent. The tuyeres are parallel-sided of 22 mm bore. The report gives slag analyses and a full metallographic examination of some of the artifacts with chemical analyses. The artifacts include a lock and a pattern-welded knife.

Factors affecting the location of the iron and steel industry in Moravia and Silesia at the time of the Industrial Revolution. M. Myska. (Rev. Hist. Min. Mét., 1969, 1, (1), 45-74 [In Fr.] The changes in the geographical distribution of the iron and steel industry in these regions, as a result of technical developments, organizational changes, changes in capital structure, and other factors, are reviewed, and detailed maps and production statistics are given.

A manufacture of white iron in the 18th century: Chenecey (Doubs). F. Laissus. (Rev. Hist. Min. Mét., 1969, 1, (1), 37-44) [In Fr.] The history of the forge at Chenecey, which produced white iron from 1700 to 1744, is reviewed.

Contribution to geography, geographical influences, and metallurgical history (Kulturgeographie) of the Niederbergisch-Markisch Hügelland. D. Düsterloh. (Göttingen Universität, Göttinger Geographische Abhandlungen No. 68, 1967, 215 pp.) [In Ger.]. A study is presented of the geographical features of the region lying south of Hattingen in Rhineland-Westphalia, and of the inter-relationships of these features with the local development of mining and metallurgy, which is described in detail from the Middle Ages to 1850.

Medieval smelting of silver in the Börzsöny Mountains. Gabor Vastagh. (Törtenelmi Szemle, 1969, (1-2), 122-129) [In Hung.]. In the 13th and 14th and at the beginning of the 15th century, silver mining was carried on in this area about 50 km NNE of Budapest. The ores contained much lead and zinc and some gold. The extent of the mining was not very great but according to some geologists the ores were very rich. Some of the medieval adits are still accessible and there are small slag heaps to be seen. Slag analyses are given and show a Ag content of 15-82 g per tonne slag, 29-260 g of Au per tonne slag, and about 1-2% PbO. The composition of the slag from an 18th century smelter was similar; work ing ceased because of the exhaustion of the ores.

No remains of the furnaces could be found apart from a few slagged stones. The author deduces that the lead-zinc ores were first roasted and then reduction-smelted so that the noble metals were recovered with the lead. Presumably this was followed by cupellation. It is claimed that the noble metal recovery was good. (100 g/tonne = 0. 01% = 3. 4 oz/ton)

'Officina ferraria', an old poem of 1612. J. Piaskowski. (Wladomosci Hutn., 1969, 25, (4), 105-109) [In Pol.]. The poem criticizes the newly introduced blast furnaces, known as 'Styrian furnaces'. Charcoal made from young fir trees is recommended if a good-quality pig iron is to be produced.

The first article made of iron in the European part of the USSR. L. A. Solntsev and L. D. Fornin. (Lit. Proizv., 1969, (11), 44-45) [In Rus.]. Three fragments of cast-iron cooking vessels were excavated near Odessa in 1964, which dated from the IVth-IIIrd century BC. Large numbers of pores were found in the specimens, which had a white cast-iron eutectoid structure consisting predominantly of ledeburite and a small amount of graphite. They contained little Si and practically no Mn. (4 refs).

Africa

Iron smelting furnaces at North Kinangop, Kenya. M. Posnansky and B. Grinrod. (Azania, 1968, 3, 1-5). The remains of a two bowl hearths or the hearths of shaft furnaces found in the Aberdare Forest region. One hearth had a slag taphole, a red clay lining and some slag in the bottom. It would appear that the internal diameter was about 1 m but there was no indication of height. The wall thickness was about 15 cm and the remains of tuyeres were also found. The tuyeres must have been about 26 cm long, tapering from 8 cm at one end to 4 cm at the other. The bore is not given. The dating is probably recent.

Asia

Iron in Iran in the first millenium BC. A. France-Lanord. (Rev. Hist. Min. Mét., 1969, 1, (1), 75-127) [In Fr.]. Physical, chemical, and metallographic studies of iron weapons and implements excavated in Luristan are reviewed. (17 refs)

An archaeological survey of south Sinai. Beno Rothenberg. (Museum Haaretz Bulletin, 1969, June, no. 11, 22-37). A preliminary report of a survey made during the 1967/68 season. This covered the turquoise and copper mines of the ancient Egyptian kings and, although copper working sites from Chalcolithic times were found, it emerges that Sinai was not a rich copper country but rather an important source of turquoise. It is now concluded that the remains found by Petrie at Wadi Maghareh and Serabit el Khadem relate to turquoise mining and not copper. The only copper site that could be assigned to Egyptian working is that of Bir Nasb where a huge slag heap testifies to prolonged metallurgical activities. The mine was located and its working dated to the 18th-15th cent BC. There was then a gap in its exploitation until further working in the Nabatean-Roman-Byzantine period.

Medieval forges at Eski Kahta, Anatolia (South-east Turkey). W. Nowothnig. (Stahl Eisen, 1969, 89, 4 Sept., 1022-1023) [In Ger.]. The results of excavations in south-east Turkey are reported and it is pointed out that the local smiths still work on the same principle as their ancestors 700 years ago. This observation is based on the composition of slags produced in medieval times and today.

Metallurgical Examination

The autonomy of the south-east European Copper Age. C. Renfrew. (Proc. Prehist. Soc., 1969, 35, 12-47.). This contains an appendix by J. A. Charles on a metallurgical examination of south-east European copper axes. These are shafthole implements and are early examples of castings made in open, but cored moulds. Their final shape was obtained by forging.

Spectrographic identification of the copper pyrites deposits in the Schattberg-Sinwell area, near Kitzbühel. H. Neuniger, E. Preuschen, and R. Pittioni. (Arch. Austriaca, 1969, 46, 99-109) [In Ger.]. Spectrographic analyses of a large group of copper ores from the Kitzbühel area of the Austrian Tirol.

The argentiferous bronze alloys of the large tetrarchic folles of AD 294-307. L. H. Cope. (Num. Chron., 1968, 8, 115-149). **Roman Imperial silver coinage alloy standards: the evidence.** L. H. Cope. (Ibid., 1967, 7, 107-129). The work of L. H. Cope will be familiar to members who have been receiving frequent reports of the work in progress. These papers discuss the more numismatic aspects of the work but also include additional metallurgical information that was not available at the time of the progress reports.

Metallographic aspects of prehistoric spear forgings. S. Modin and L. Thålin. (Jernkont. Ann., 1969, 153, (5), 31-239). [In Swed.]. The spear heads are described and results are discussed in the light of general knowledge from other archaeological finds.

Examination of a dagger of Luristan type. R. Pleiner. (Arch. Anzeiger, 1969, Part 1, 41-47). [In Ger.]. The metallographic examination of a Luristan iron dagger or short sword from the Museum at Solingen. The hilt is of iron with the composite method of construction, in which the various pieces are mainly held together with rivets and bands. The carbon content varies from ferrite + pearlite to the eutectoid and the carbide is almost entirely spheroidized, as is usual in this type. A chemical analysis of the blade gave a Ni content of 0.4%, which suggests that it was either made from a nickeliferous ore or that it incorporated a piece of meteoric iron. The date is given as 8th-7th cent. BC.

Techniques

On a method of rendering platina malleable. W. H. Wollaston. (Metallurgical Classics, pages 573-604: Published by the American Society of Metals. Ohio, 1967). One of a series of reprints of significant papers in metallurgical research and inquiry, presented with contributed interpretive commentaries, biographical sketches and notes. The series is edited by J. H. Westbrook and the commentary in this example is by Prof. J. Gurland of Brown University.

The early history of casting moulds and the science of solidification. C. S. Smith. (Metal Transformations, Informal Proceedings of the 2nd Buhl International Conference on Materials, New York, 1968.) An excellent account of the early history of casting.

The development from Damascus steel to Scharsach steel: the improvements of sword steels from the La Tène period to the late Middle Ages. C. Böhne. (Arch. Eisenh., 1969, 40, Aug., 661-665) [In Ger.]. The manufacturing techniques for sword blades from the 3rd century BC to the 14th century AD are traced, and the various improvements which were made during this period are described and the reasons for them considered. (10 refs.)

Technique of fabrication and research into the provenance of copper artefacts of the Remedello culture. L. Matteoli and C. Storti. (Accademia de Scienze e Lettere, Instituto Lombardo, 1967, 101) [In Ital.].

Experimental smelting of steel in early medieval furnaces. R. Pleiner. (Památky Arch., 1969, 60, 458-487) [In Eng.]. A report of a smelting programme covering the Zelechovice type of Moravian furnace of the 8th cent. AD and the Scharmbeck-Drengsted type of furnace of the first few centuries AD. Reasonably successful smelts were obtained with the former but it was found impossible to make the latter work with induced blast. Full details of the ore, method of working and composition of the products is given. The charcoal was made on the site of the experiment and the results of this part of the work form almost the only scientific information on the charcoal-making process.

Iron smelting experiments in a reconstructed Roman furnace. Henry Cleere. (The Iron and Steel Institute, 1970, 32 pp.) The paper reports a series of experiments carried out in a low-shaft furnace of the type discovered by the author at Holbeanwood, Sussex (Bulletin, 1969, 3, (1), 28-29), using Wealden carbonate ore and charcoal. In the most successful smelt, a 10 kg bloom was produced; slag corresponding to archaeological finds at the Holbeanwood site was also made. The ore was roasted in trench type furnace of the type found at the nearby Bardown site, but the degree of calcination achieved was less thorough than that evidenced by archaeological finds.

Slags

Constitution of bloomery slags: Part I—Roman. G. R. Morton and J. Wingrove. (J. I. S. I., 1969, December, 1556-1564.). The results of work that is still continuing. These show that the principal slag phases are wüstite, fayalite, and anorthite, and that magnetite where present is either formed on cooling in oxidizing conditions or on long exposure to the atmosphere. The proportion of phases present may be calculated from the chemical composition and the approximate melting temperature of the slag, and the working temperature of the furnace may be calculated by plotting the % of the three main components on the relevant phase diagram. Results confirm that the average working temperature was 1150-1200 °C.

Identification of iron oxides. Joyce Wingrove. (J.I.S.I., 1970, March, 258-264). Physical examination of iron oxides present as primary phases in a Roman bloomery slag and in synthetic slags has shown that the oxides FeO, Fe_3O_4, and Fe_2O_3 crystallize in forms which are visually recognizable by microscopic techniques. In addition their microhardness differs by small but significant values. The form of crystallisation of wüstite and magnetite is in general agreement with that indicated by consideration of their thermodynamic properties.

Biography

An early history and some unrecorded incidents of Round Oak Steel Works. W. H. B. Hatton. (Acorn, 1969, Summer, 7-14). The author was joint managing director from 1936 to 1950, and is the son of the managing director from 1897 to 1924. He worked for the company from 1899 to 1950. In this first part of the article he relates incidents, developments, and personalities, including the introduction of Edrow Rust Resisting Steel and the use of the Bertrand-Thiel steelmaking process.

Parkbridge: an historical ironworks. J. Holland. (Man Metal, 1969, 46, Nos. 6, 7, 8 (June, July, Aug.), 163-4, 186-7, 214-5). Some personal reminiscences are given, with a brief history of the Parkbridge Works of Hannah Lees and Sons Ltd, near Ashton-under-Lyne (c. 1670-1964). The author describes the work of the tongsmen in the old hand rolling mills and of the furnacemen among whom he worked, from 1924, when he joined the company as an apprentice.