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Contents

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The cover illustration is of Dr John Percy FRS (1817–88) the first director of the Royal School of Mines, President of the Iron and Steel Institute 1885–87 and author of the series of books, first appearing in 1861 which have come to be known simply as 'Percy's Metallurgy'.

Metallurgical investigation of Roman lead pipes from Pompeii

W W Krysko and R Lehrheuer ©

SYNOPSIS

The Romans were extremely practical metallurgists, and a present day examination of their lead sheeting reveals that it was deformed solely for the purpose of providing a desired shape, and any change in the grain structure was purely coincidental. On the other hand, deformation of copper and bronze had a twofold purpose: to provide a shape and also to strengthen the material. We should avoid drawing conclusions from our present knowledge of materials to say what the manufacturing methods of the past were for. The strengthening effect on lead, due to its low recrystallization temperature, is negligible during coldworking, and the long term beneficial corrosion effect could not be expected to be a problem to concern the ancient metallurgists.

By courtesy of the Soprintendenza alle Antichita delle Province di Napoli e Caserta (Sig. A. de Franciscis), pieces from two Roman lead water pipes from Pompeii were sent to me at my request for investigation (Figures 1 and 2) 2). As can be seen from Figure 1, one piece was unfortunately broken in transit.

The samples to be investigated were embedded in self-setting resin (Trade Name: Technovit) and any necessary cutting of the samples was done after the embedding, thus avoiding damage. Preparation of the pieces for microscopic investigation was done by consecutive grinding and polishing operations with wax-coated emergy paper, grain size 0; 2/0; 3/0 and 4/0. The use of a wax-coated paper was necessary in order to avoid impregnation of silicon carbide particles into the lead surface. The samples were then given a chemical polishing treatment in a solution of 80 ml glacial acid (99%) and 20 ml hydrogen peroxide (30%). Some samples were microscopically examined and photographed and others were additionally treated by etching in a Vilella solution of 8 ml nitric acid (1.40 specific gravity), 8 ml glacial acid (99%) and 84 ml glycerol, for a few seconds, so as to reveal the grain structure and segregation phases.

For the main investigation, the samples were subjected to optical microscopy, followed by hardness testing, and finally scanning electron microscopy (Cambridge) with combined multi-channel analyzer. The results obtained from investigating the oval cross-section (Figures 3 and 6) were as follows:

The outside diameter of the pipe samples was 30mm to 40mm with a wall thickness of 5mm. From the grain structure it can be deduced that the lead, after being cast as a long flat sheet approximately 6mm thick, was rolled over a mandrel to form a pipe. A gap was left between the edges of the pipe, and refractory material (probably a clay-sand mixture) was placed along the gap to form a longitudinal trough. The inside mandrel of the pipe and the longitudinal trough formed a casting mould into which molten lead was poured, which in turn remelted the edges of the lead and, on solidifying, formed the final lead pipe.

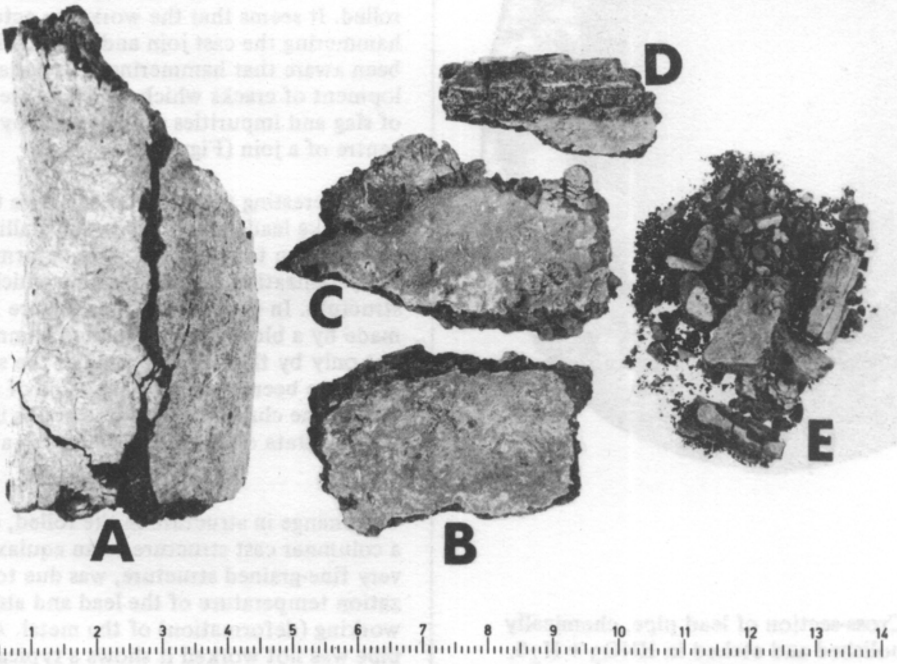

Figure 1 Lead pipe from Pompeii. D. represents the longitudinal join seen in Figure 5

Figure 2 Lead pipe, the cross-section of which is seen in Figure 3

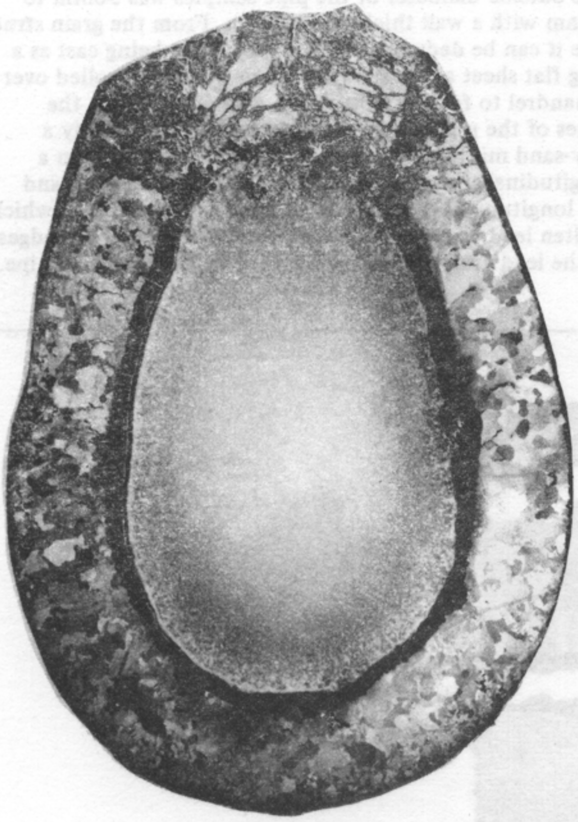

Figure 3 Cross-section of lead pipe, chemically polished and etched in $HNO_3 + H_2O$.

During the flattening and following rolling process the cast structure of the lead sheet was changed but this deformation of the material would not have been sufficient to produce the the fine, equiaxed grain structure seen in Figure 3. We can therefore deduce that probably after the joining of the edges by the cast lead welding method, the pipe was well and evenly hammered along its entire surface, except for the area of the cast join. The hammering was done in order to enlarge the diameter of the pipe, and not to produce grain refining by working and a consequently stronger finished product, because if the latter had been so, the cast join would also have had to be worked over. By enlarging the cross-section of the pipe by hammering, and without hammering the join, an oval section was created, and this manufacturing step was carried out so that the pipe could be removed from the mandril around which it had been rolled. It seems that the workman actually avoided hammering the cast join and it is possible he may have been aware that hammering occasionally leads to the development of cracks which we know are due to large amounts of slag and impurities accumulated by segregation at the centre of a join (Figure 4).

It is interesting to note how sensitive to deformation is a metal like lead, which has a recrystallization temperature below room temperature. Any deformation produces, by recrystallization, a grain refining which leads to a fine-grain structure. In the left centre of Figure 3, the indentation made by a blow from a rounded hammer can be recognised, not only by the slight denting of the surface, as this could also have been caused by any type of abrasion or cutting, but by the cluster of very fine grains in a concave form in the substrata of the indented area – a clear indication of impact.

The change in structure in the rolled, cast lead sheet, from a columnar cast structure to an equiaxed – and for lead a very fine-grained structure, was due to the low recrystallization temperature of the lead and also to the extensive working (deformation) of the metal. As the join of the pipe was not worked it shows a typical cast columnar grain structure with the direction of the solidification front advancing from the interface of the remelted edge towards the central plane of the cast portion.

The remelted interface, having a fine globular grain structure, from which delicate needle-like columnar grains extend and grow into large columnar grains, indicates that the temperature of the lead used to produce the join was carefully controlled and is a sign of skilled craftsmanship.⁽¹⁾ The neglect shown in preventing surface lead oxide (dross) (Figure 16), which could easily have been eliminated but has been allowed to enter the casting, is in contradiction to the careful control of the melting temperature. Nevertheless, it has to be admitted that even today, in spite of modern melting equipment and control, failures due to dross inclusions in lead articles sometimes occur.⁽²⁾

From Figure 4 it can be seen that the join of the solidifying metal has produced a contraction pipe. This was not apparent at the time, but due to the process of corrosion over the centuries, a predominantly straight corrosion track has formed. The corrosion is dominant in the areas of columnar cast structure (Figure 3), and from Figure 3 it can also be seen that the starting point for the greatest corrosion was the actual piped area. In Figure 5 a longitudinal cross-section of the join, cut at a slight angle to make a large number of columnar grains visible, can be seen. The corrosion proceeded along the straight planes of the grain boundaries between the columnar grains, and arriving at the interface where there were equiaxed grains, found it considerably more difficult to advance in the maze of the equiaxed structure and so petered out. We should consider that the process of corrosion has been continuing in these samples for the last 1900 years or so.

The product of corrosion appears to be mainly lead oxide. Where the lead oxide appears in a reddish-brown shiny form resembling polished wood (Figure 6 †), it is in a well-developed, hard, sintered, crystalline pattern (hardness: 61.5). Where it appears in a powdery, greyish-black form, it is in an unsintered, powdery form. These forms continue into the metal with the progressive disappearance of the reddish-brown pattern (Figure 7 and 8)

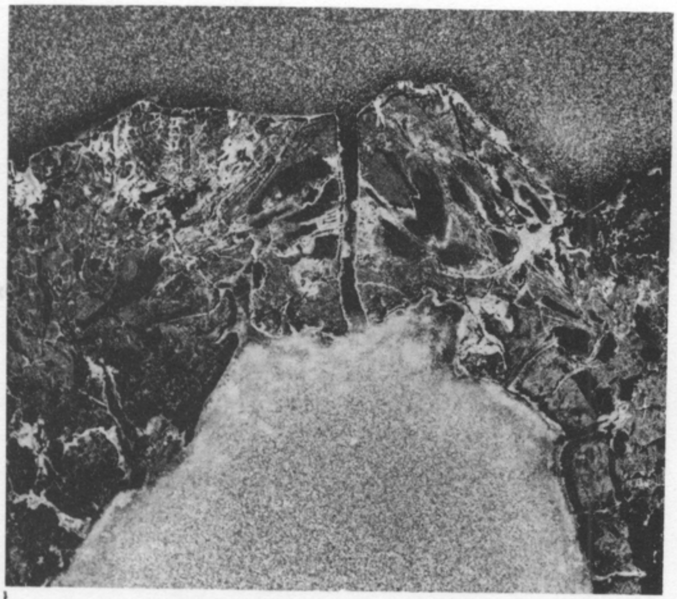

Figure 4 Pipe formation within the joining plane of the cast columnar structure, made visible by a corrosion track completely penetrating the cross-section.

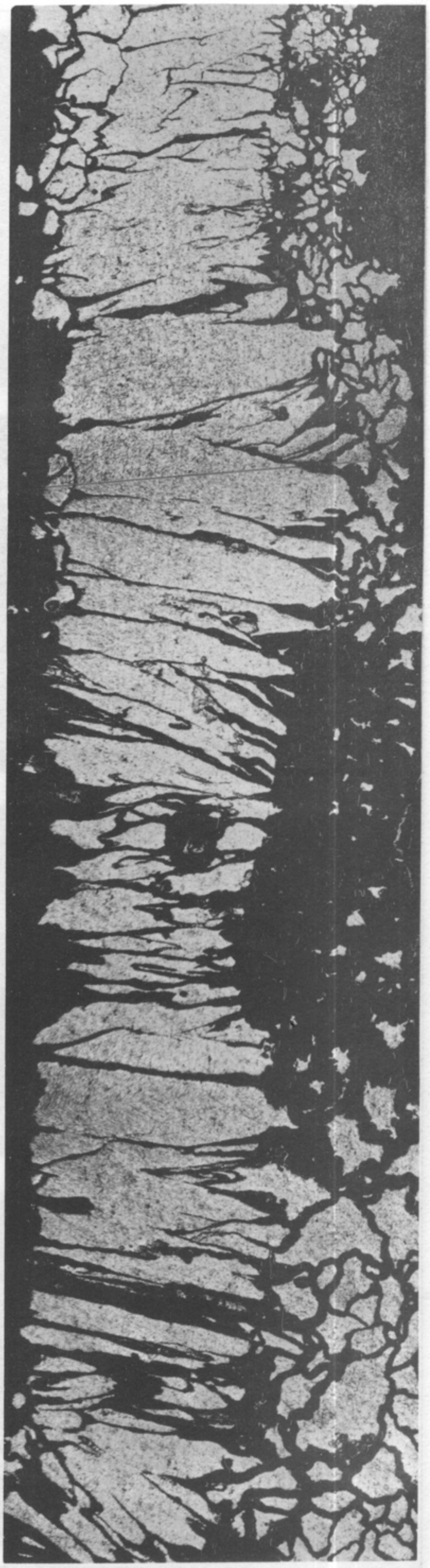

Figure 5 Longitudinal cut through the joining area, revealing the columnar cast grains and the interface of the transition area between the columnar and equiaxed grains. Magn. 12x.

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† Figure 6 is in colour and can be seen on application to the Hon Editor

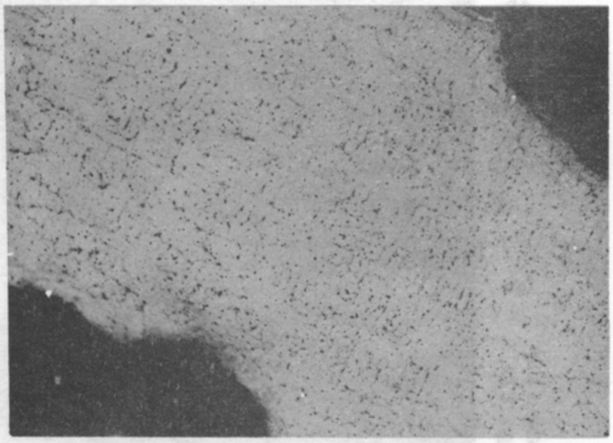


Figure 7 A long streak of well-crystallized, reddish-brown lead oxide, surrounded by powdery, greyish-black lead oxide. Mag. 50x.

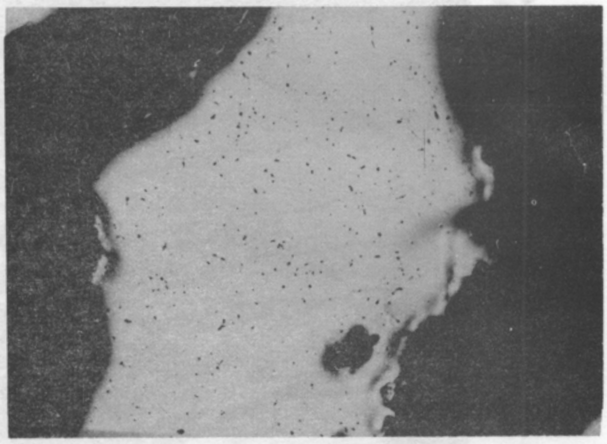


Figure 8 Further away from the main corroded areas, the reddish-brown lead oxide appears only as short streaks or islands surrounded by powdery, blackish lead oxide. Mag. 50x.

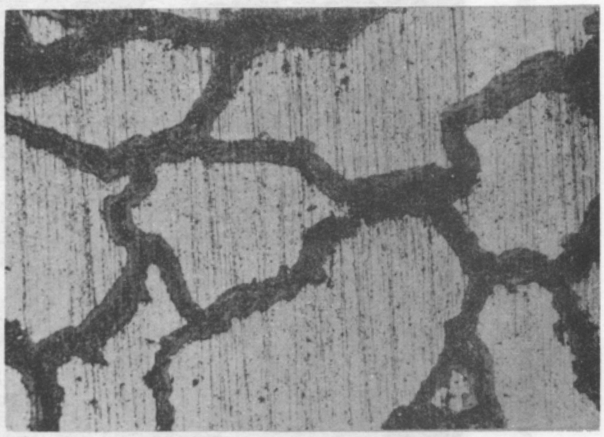


Figure 9 The columnar grains which are close to the joining plane show few impurities due to the slow rate of solidification. Magn. 100x

Figure 10 Grains at the centre of the columnar grain area, showing an increase in impurities. Magn. 100x

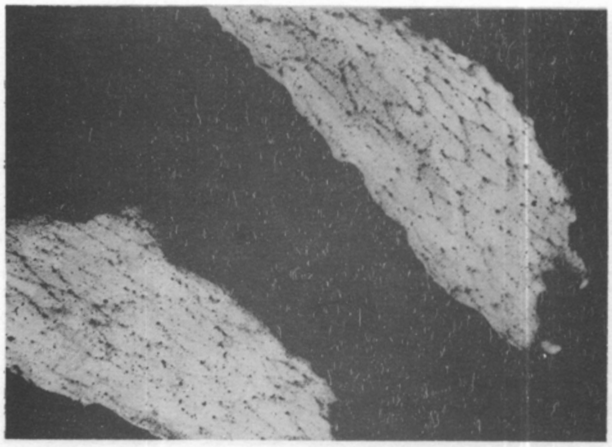


Figure 11 Grains at the starting plane of the columnar grains with additional increase in impurities, which have led to segregation along the sub-grains. Magn. 100x

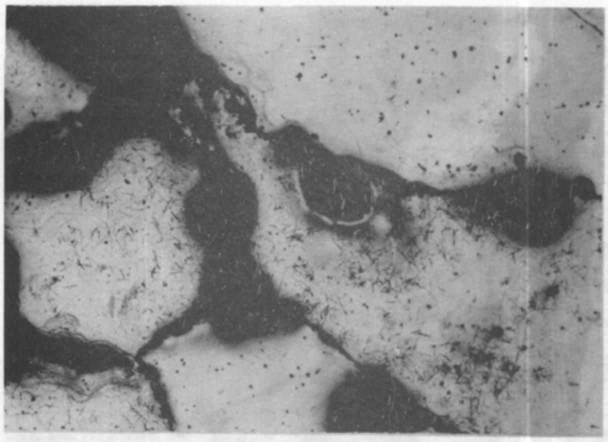


Figure 12 The interface of the columnar-equiaxed grains. Magn. 100x

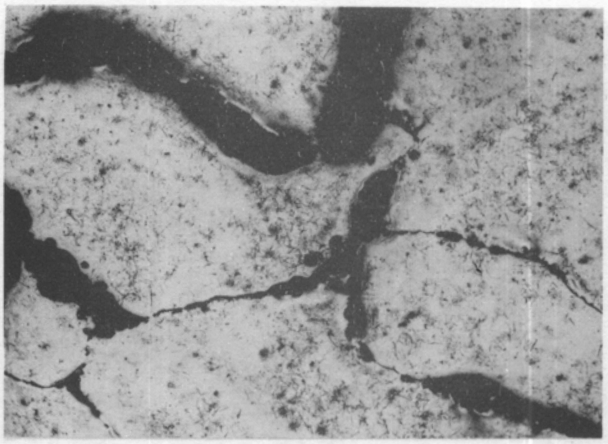


Figure 13 Progress of corrosion into the equiaxed grain area. Magn. 100x

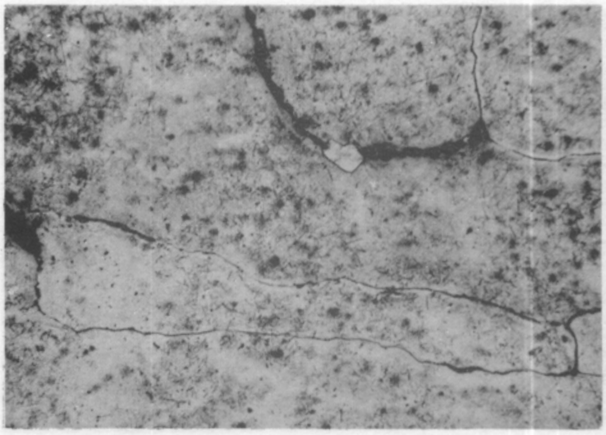


Figure 14 Restriction of intercrystalline corrosion in the maze of the equiaxed grains. Magn. 100x

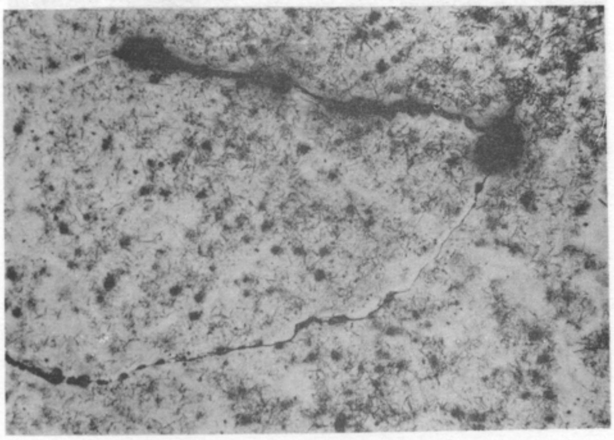


Figure 15 Intercrystalline corrosion proceeding along a grain boundary. Magn. 100x

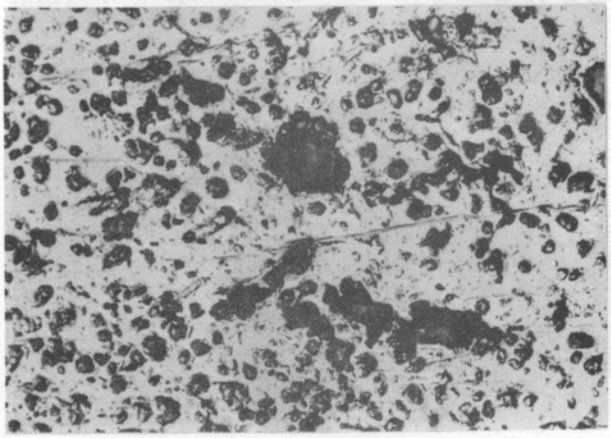


Figure 16 An area of heavy dross inclusions (suspended lead oxide originating from the melt) due to a fast rate of cooling near the welding interface. Magn. 200x

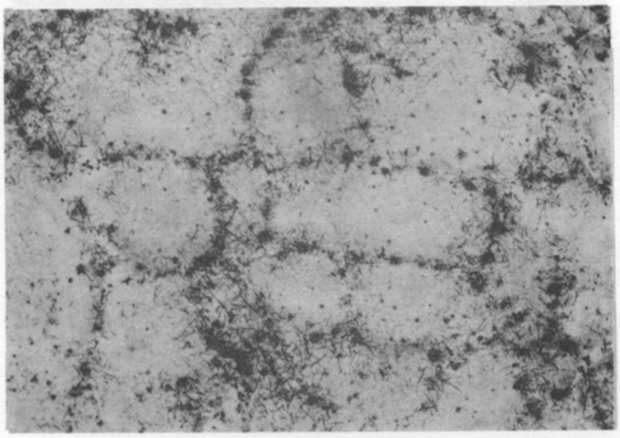


Figure 17 Segregation of copper precipitates along the boundaries of the subgrain structure due to a greater amount of copper in the melt combined with a fast rate of cooling. Estimated Cu content: 0.02%. Magn. 200x

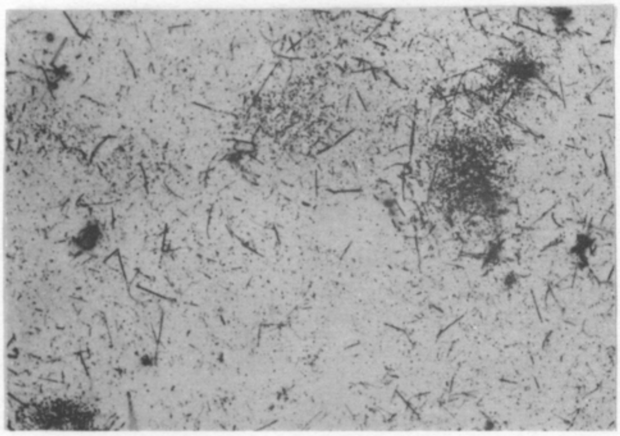


Figure 18 Long-term isothermal precipitation of zinc needles due to overageing of a supersaturated solid solution. Estimated zinc content: less than 0.1%. Magn. 200x

Microscopic examinations of selected areas were carried out in order to examine the progressive change in the grain structure from the columnar grains of the cast join towards the equiaxed grains of the worked lead sheet. The grains show a considerable range of difference in purity, so we can assume that the lead used was not of the best quality available at the time. There is a marked gradient of increased impurity extending from the last solidified area of the join towards the remelted zone (Figures 9 to 15) and this can be explained by the solidification gradient: the slower the solidification, the more time is available for the suspended and precipitated impurities to be segregated by buoyancy in the liquid state.[3,4] Figures 9 and 10 show columnar grains embedded in their corrosion products and these grains appear to have no noticeable segregate or impurities. Figure 11 shows two columnar grains which lie closer to the interface and have copper segregate along well-pronounced subgrains. Figure 12 shows the transition region between the columnar grains and the remelted lead sheet. Figures 13, 14 and 15 show the equiaxed and worked sheet metal in which the corrosion was progressively decreasing. It can be concluded from all these examples that the corrosion is intercrystalline, that it progressed along the straight grain boundaries of the columnar structure, and on reaching the transition area, followed the intricate pattern of the equiaxed grains and became progressively restricted. All figures 9 to 15 are magnified 100x linear.

The basic impurities in the lead seem to be:

1. Lead oxide in the form of dross entrapped in the solidifying lead due to insufficient care during the process of casting, as well as a rate of solidification which prevented separation by buoyancy (Figure 16).

2. Copper segregate along the subgrain boundaries due to precipitation of a supersaturated solution as well as high supersaturation during the fast cooling of the melt (solubility limit = 0.05% Cu at the melting point), and a decrease of solubility in the solid state producing extended precipitation (Figure 17).

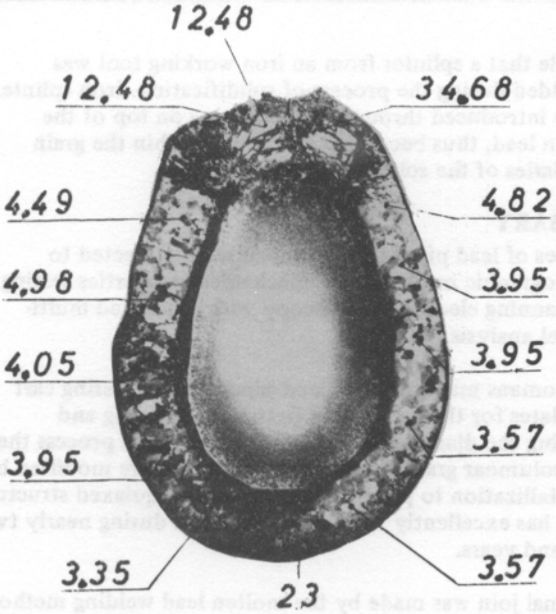


Figure 19 Hardness test results and the testing position along the cross-section of the lead pipe. Ultratester: Indenter P; Load 200N; Loading Time 60 secs.

3. Isothermal, long-term precipitates in the solid state due to supersaturation with copper and zinc (solubility limit = 0.04% Cu and 0.004% Zn[5]. These precipitates occur in fine, needle-like patterns after very long periods (overageing) (Figure 18).

From the microstructures we can assume that the molten lead may have had a copper content of about 0.05% and 0.1% Zn.

Data which are to hand relating the change in hardness to the amount of mechanically entrapped dross expressed as oxygen content in ppm, gave the mean values presented in the Table below. This led to an investigation of the hardness of the cross-section, as seen in Figure 19.

Table of hardness values and the closest available oxygen content corresponding to the hardness values.

Hardness test values	O_2 content in ppm	Remarks
62.5	Not available	Reddish-brown oxide.
34.68	Not available	Pb grains surrounded by oxides.
12.48	Not available	Pb grains surrounded by oxides.
4.50	48.00	Large amount of dross in grain.
3.98	40.00	Large amount of dross in grain.
3.50	30.00	Dross mainly in grains.
3.25	13.00	Dross mainly on grain boundaries.
2.50	5.40	Dross only on grain boundaries.

The oxygen solubility at the melting point of lead is 0.08 ppm. All higher amounts of oxygen are due to inclusions of suspended dross during solidification and not to oxygen solubility.[3]

To determine the hardness, a specially designed hardness tester was used which could determine the depth of penetration under full load and give the results for a fixed time with digital readings. The progress of indentation could also be recorded on an X–Y recorder, showing the rate of short-term creep (Figure 20). From the X–Y recorder graphs the hardness of a brittle body like lead oxide could be calculated from the starting slope of the graph. This tester, designed and constructed at the Institut fur Werkstoff-technik, Technische Universitat Berlin, is to be marketed under the name Ultratester (Wolpert) and will be available from 1976.

The centre of the cast flat plate formed the bottom of the rolled pipe (Figure 19) and the hardness figures are lowest at this point and increase on both sides of the pipe towards the upper join. From this we can deduce that the flat cast lead sheet, from which the lead pipe was produced by rolling, solidified last, at the centre line, giving there the most beneficial conditions for a separation of dross by buoyancy.[4] Towards the edge of the cast flat lead plate the rate of solidification increased and also the amount of dross, and therefore the hardness figures increased. The area of the cast join produced after rolling has been so heavily corroded that even with a light indentation from the tester the hardness values of the lead in that area are greatly influenced by the values of the surrounding harder lead oxides.

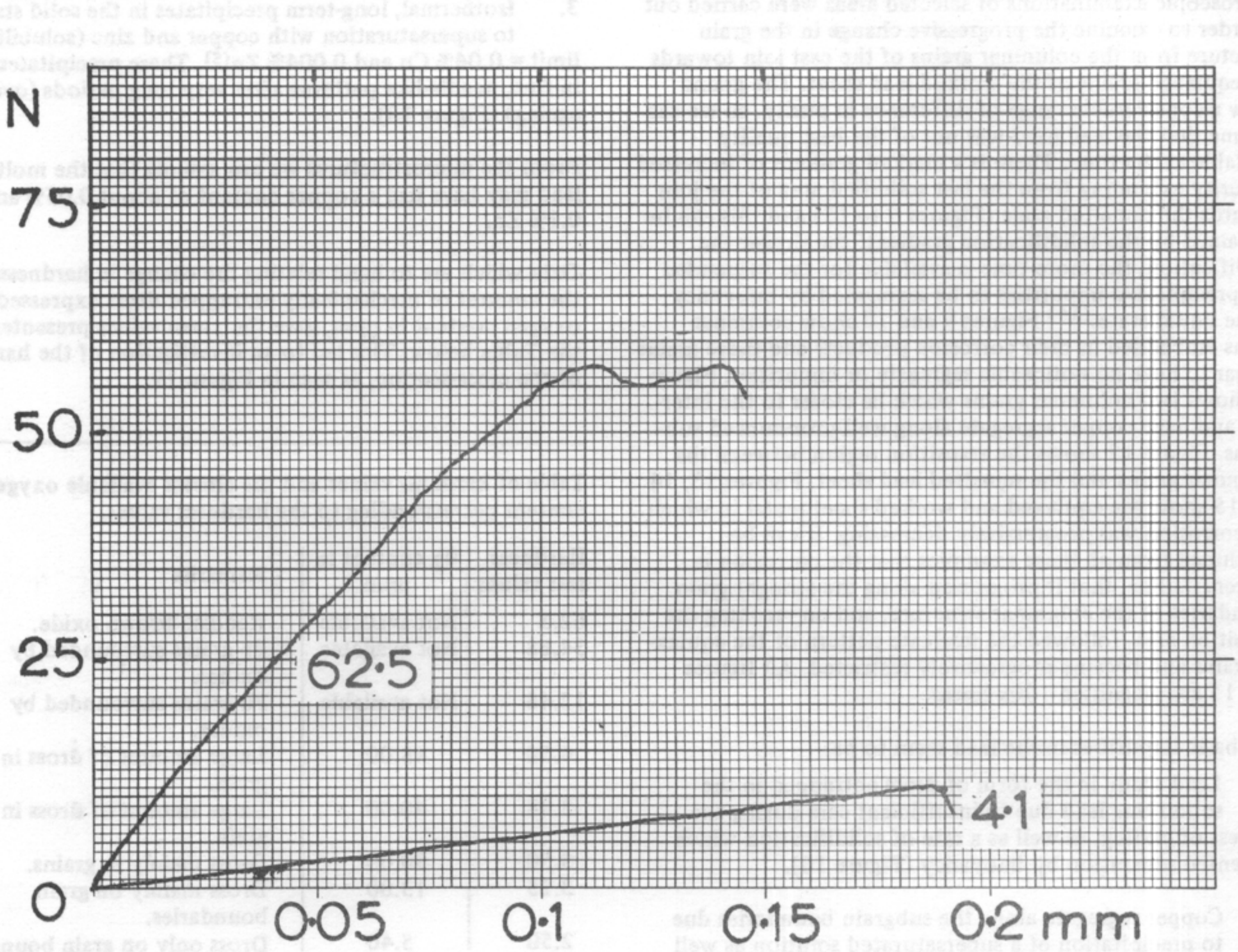


Figure 20 Recorded load deformation graph of hardness test. The upper graph shows the test on the well-crystallized lead oxide, giving a hardness of 62.5. The lower graph, for lead, gives a hardness of 4.1. The unsteadiness of the upper graph is due to cracking of the brittle structure.

Providing the right equipment is used, hardness testing when applied as in the present instance is simple and speedy and gives a picture of the distribution of inhomogeneities and inclusions equivalent to lengthy and costly microscopic and/or chemical analyses.

The scanning electron micrographs show that the contours of the lead which are revealed after the corrosion products have been dissolved, are well-developed and the surface of the lead grains at the intercrystalline, corroded grain boundaries is smooth. The corrosion itself proceeded along the grain boundaries which are an area of higher density imperfections and resulting higher stresses.

There is no indication of corrosion penetration into the grains themselves other than a gradual flat transfer of lead into lead oxide along the entire grain face.

These observations are an indication of a long term steady corrosion effect, typical of lead with only a pronounced intercrystalline corrosion pattern (Figures 21(a) and (b)). The impurities revealed by the multi-channel analyser were mainly copper and zinc (Figure 21(c)). In Figures 22(a) and (b) a peculiar 'bridge' across a grain boundary was discovered and an investigation of this bridge with the multi-channel analyser (Figure 22(c)) revealed it to be a fine iron spike. An explanation for this cannot be given, but it is possible that a splinter from an iron working tool was embedded during the process of solidification. Iron splinters can be introduced through dross floating on top of the molden lead, thus becoming embedded within the grain boundaries of the solidifying lead.

SUMMARY

Samples of lead pipes from Pompeii were subjected to metallographic investigation, mechanical properties testing and scanning electron microscopy with combined multi-channel analysis.

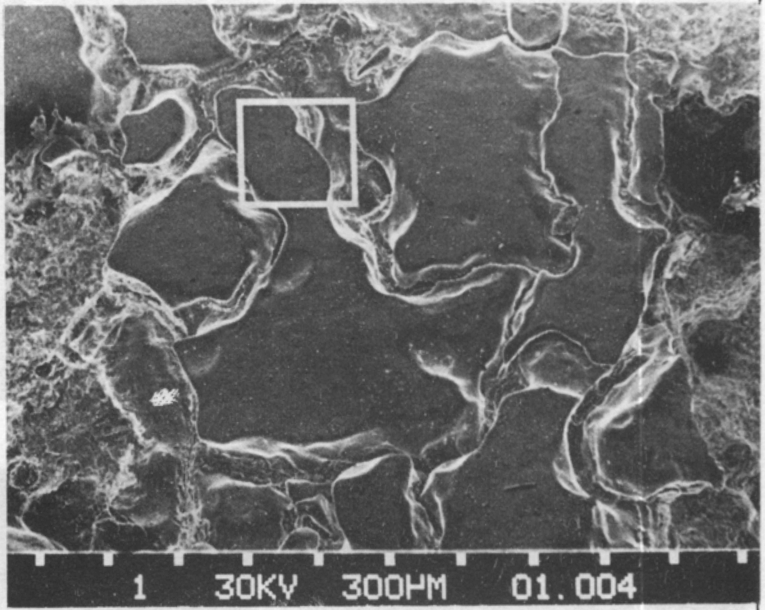
The Romans manufactured lead pipes by hammering cast lead plates for the purpose of flattening, bending and enlarging the diameter of the pipes. During this process the large columnar grains of the cast structure were modified by recrystallization to produce a fine-grained equiaxed structure which has excellently withstood corrosion during nearly two thousand years.

The final join was made by the molten lead welding method and the structure of unchanged cast columnar grains remained. and proved to be prone to corrosion attack. The grains of this structure are completely embedded in corrosion products and metallic connection between the grains is lost. The corrosion is of the intercrystalline type. From this it can be deduced that the Romans did not recognise the grain-

refining action on lead produced by hammering at room temperature, as otherwise the cast structure of the join would have been given the same beneficial treatment.

A large amount of suspended dross (surface oxides of molten lead) was introduced during the casting. Precipitation of copper along the grain boundaries of the subgrains and a long-term isothermal precipitation of zinc needles (overageing) was detected.

21a



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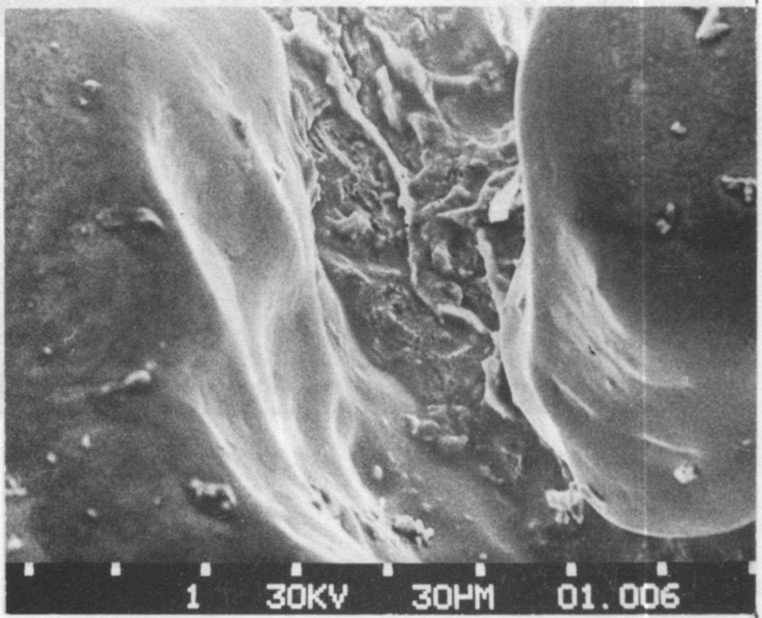
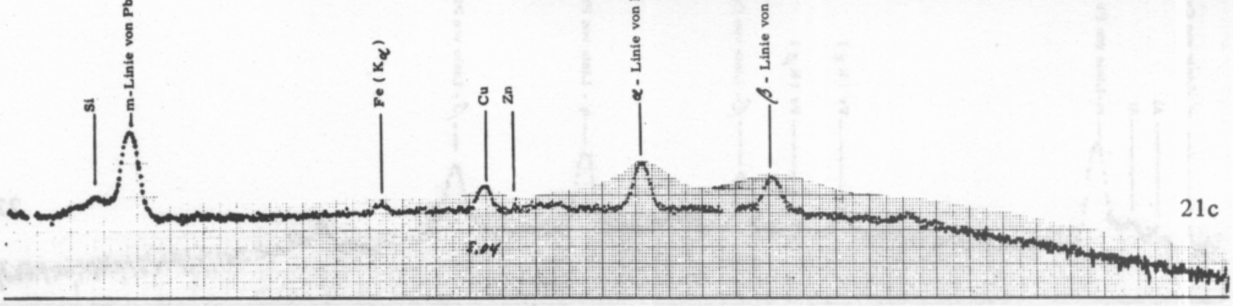
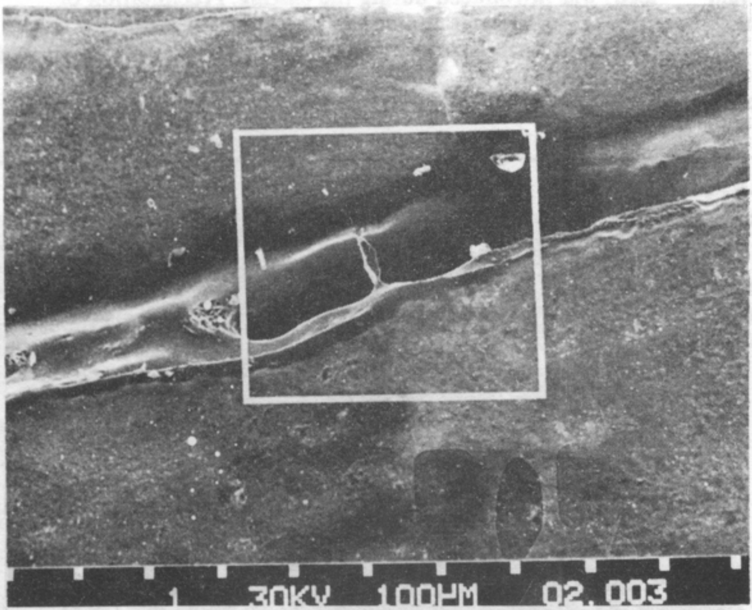




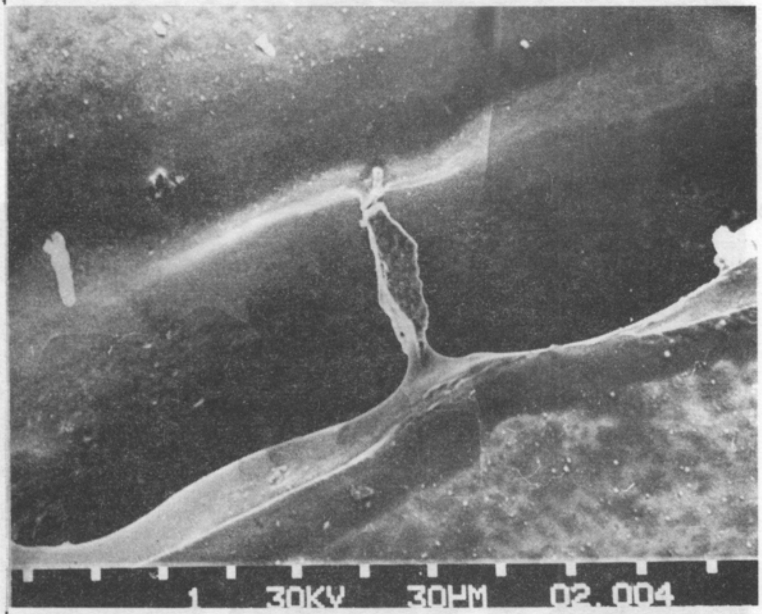
21c

Figure 21 **(a) and (b). Scanning electron pictures of the intercrystalline corrosion proceeding smoothly along the grain boundaries. (c) Multi-channel analysis of the basic material, revealing the main impurities in the lead to be copper and zinc.**



22a

Figure 22 (a) and (b). Scanning electron pictures of the area of join, revealing a peculiar spike which was analysed by the multi-channel analyser as being iron. (c) Multi-channel analysis of the spikey inclusion, which withstood the dissolving action of the solution used to remove the corrosion products. The analysis showed the spike to be mainly iron. Other impurities are copper and traces of aluminium and silicon, the last two most likely from refractory inclusions.



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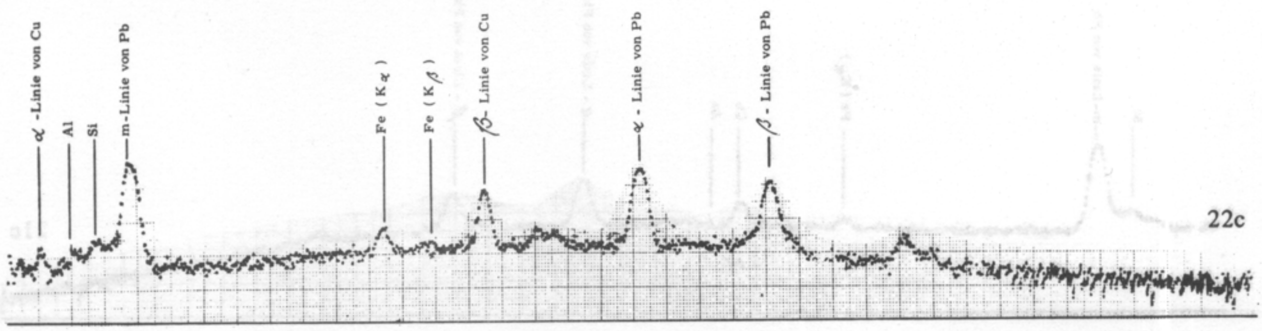

22c

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APPENDIX

A comparison can be made with a cross-section (Figure A) of a heavily corroded waterpipe, approximately 100 years old, manufactured by the extrusion method. It can be seen that the corrosion pattern is also intercrystalline and is controlled by the grain shape and size. However, due to the difference in materials flow during the extrusion process, the grains in this example are much more varied in size and shape than those in the hammered section of lead pipe from Pompeii. The corrosion proceeds along the grain boundaries attacking mainly the coarse grain structure, which is dominant in this case, with a resulting severe corrosion of a large area of the extruded lead pipe.

The Pompeiian waterpipe has coarse columnar grains only in the area of the join made by the molten lead welding method, with severe corrosion localised in this area.

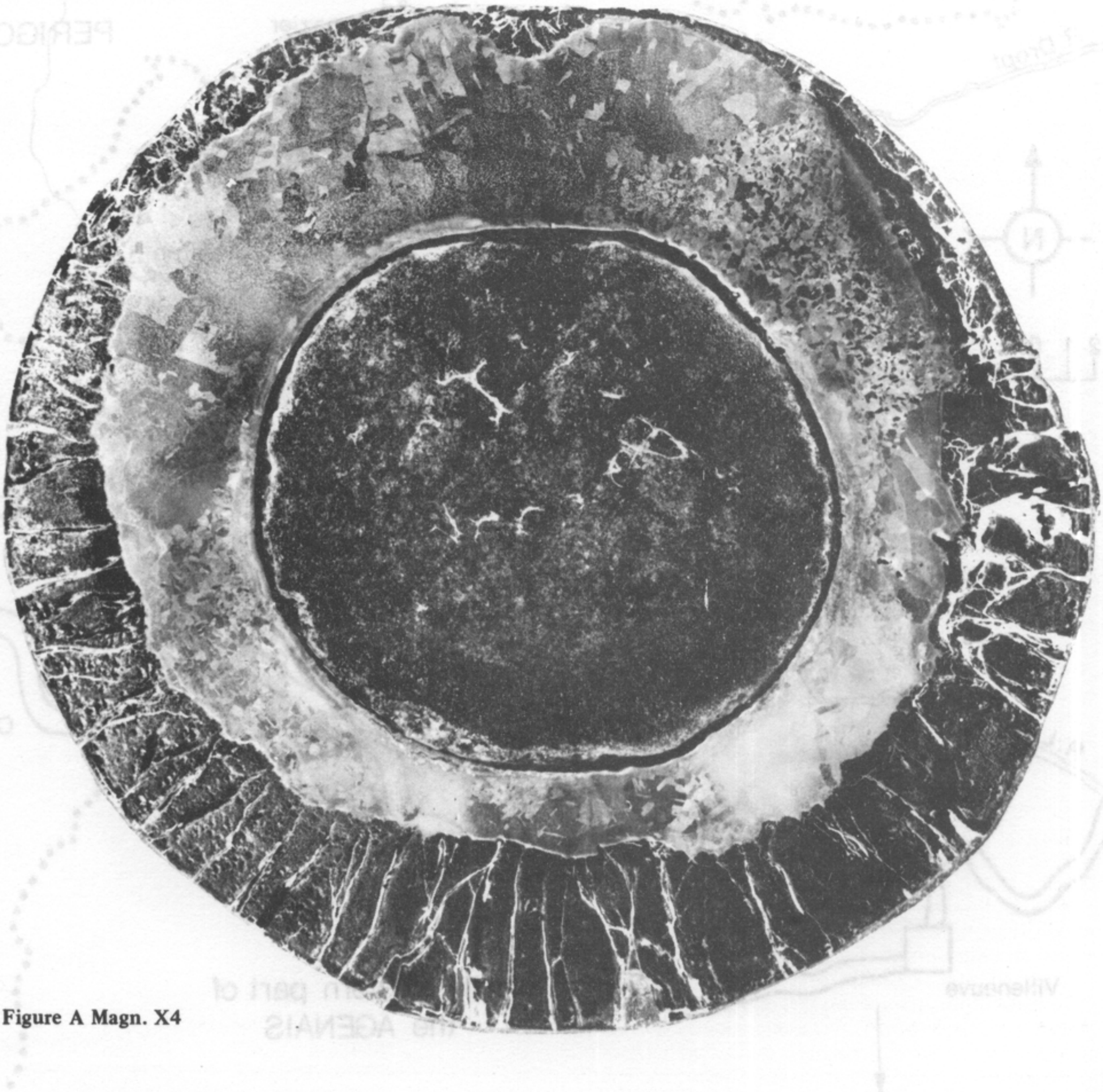

Figure A Magn. X4

Charcoal iron making

Norman Mutton ©

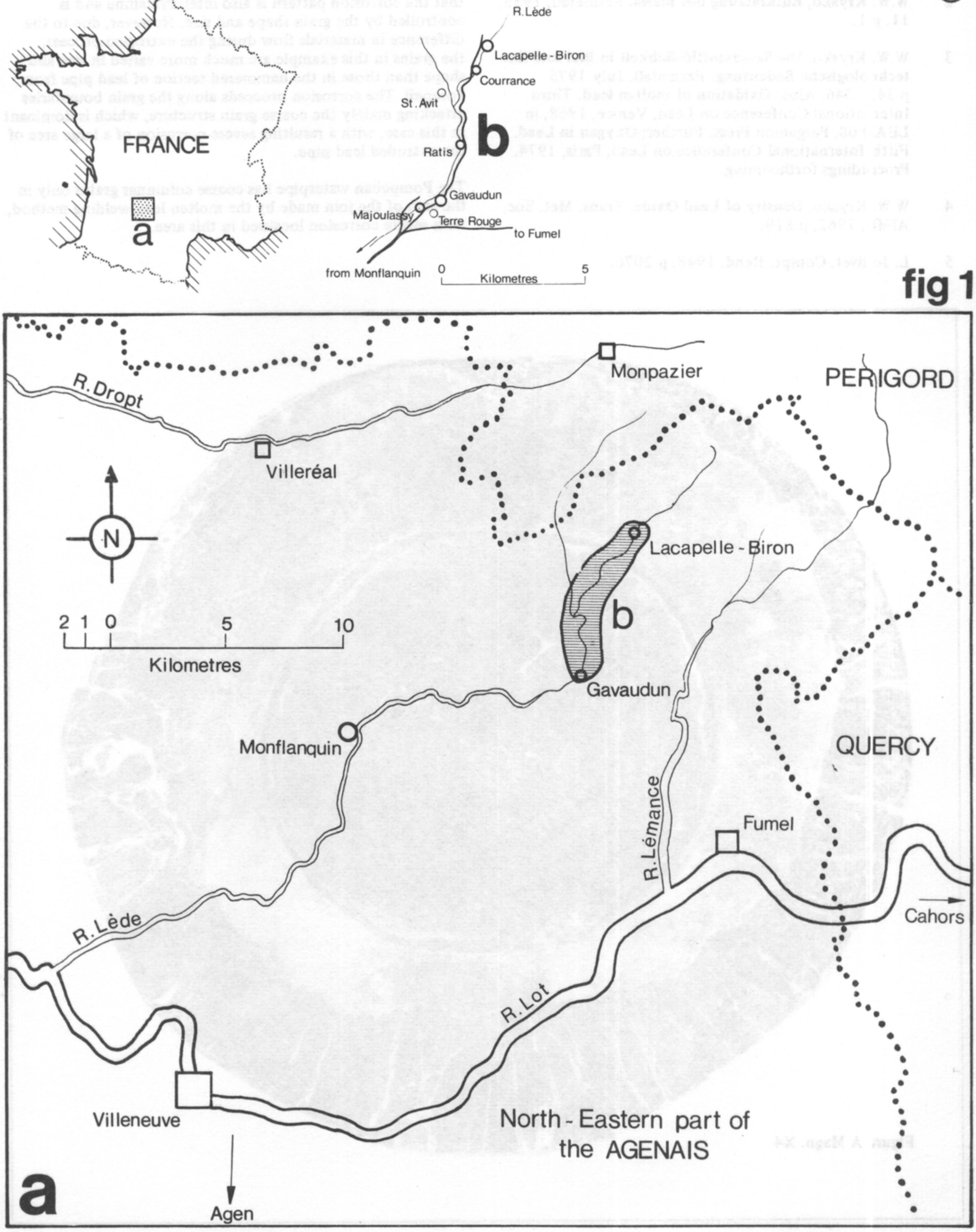

fig 1

in the Département of Lot-et-Garonne, France

The former French county of the Agenais, now the Département of Lot-et-Garonne, lies to the south of Périgord and to the west of Quercy. (Figure 1). The north-eastern part of the Agenais had a well-established but little known charcoal iron industry for perhaps 400 years.(1) There are, in the Departmental Archives at Agen, some deeds, 18th and 19th century official reports on local industries, and applications for industrial licences under a law of 1810. This mainly legal and administrative evidence about the industry has been studied and published in a comprehensive form by Mademoiselle Bourrachot, assistant archivist at Agen(2). With this one exception it has had little attention from French scholars(3), and is virtually unknown to British students of historical metallurgy.

Although the earliest dates must remain conjectural, evidence for the industry dates back to the mid-fifteenth century. Some 20 sites have been noted. The industry was of more than local importance in the 17th and 18th centuries and survived to the middle of the 19th century. By 1850 the district had acquired its first, and only, coke iron blast furnace plant at Fumel, which is still an active part of the Pont au Musson group of companies(4). Soon after 1850 the charcoal iron industry, which had been declining since the end of the Napoleonic Wars, ceased altogether.

The industry of the Agenais consisted of two distinct types of ironmaking using totally unrelated methods(5). There was a number of Catalan forges which produced bar iron by a direct process from the local ore. There were also small charcoal blast furnaces with their associated Walloon forges, ie. finery and chafery, for the indirect production of bar iron, and for the production of a range of castings, especially pots. The whole industry depended essentially upon isolated pockets of hematite found in a few square kilometres around the villages of Gavaudun and Lacapelle-Biron, near the bastide of Monflanquin. (Figure 1). There were small, often inadequate, supplies of timber for charcoal making to be had in the immediate neighbourhood, and other supplies were imported from Périgord Noir. Water power was supplied by four small rivers, le Dropt, la Thèze, la Lède, and la Lémance, although they were chronically short of water to supply power enough for the forges, furnaces, mills and paperworks which averaged one per kilometre along their courses(6).

So far as I have been able to discover, there is little evidence extant about any of these small ironworks, or of their precise working methods, costs or outputs(7). Similarly there is no evidence that the sites had been studied by anyone interested in historical metallurgy, nor that any samples of ore etc. had been collected and analysed in order to make some comparison with other comparable charcoal iron industries. I therefore tried to look at some of the physical remains and to collect samples for analysis. I had become interested in the area after a holiday in 1971, and in 1973 I revisited it. In the limited time available I travelled the length of the three biggest river valleys to ascertain the general siting of the industry up to the middle of the 19th century, and incidentally that of its successor at Fumel. I looked closely at two ironworks sites and one ironstone quarry, but had insufficient time to investigate another forge site as I had hoped to do. All these lay in the valley of the river Lède. In that valley there were formerly these three ironworks all lying in the contiguous communes of Gavaudun and Lacapelle-Biron, the centre of the scattered ore supplies. From north to south, over about 5 kilometres in the spectacular valley of Gavaudun they were: la Courrance, on the southern boundary of Lacapelle-Biron, near the small hamlet of St. Avit; Ratis, further downstream nearer the village of Gavaudun; and Majoulassy, on the southern boundary of the commune of Gavaudun. (Figure 1).

The following gives the summarised history of each of these three ironworks, and a note of the conditions in 1973.

Courrance(8)

It seems that this works was established, by the family Trubelle, only shortly before the Revolution of 1789. During the Revolution orders from the State ensured a precarious livelihood, but the works were far from any good road, and too near the source of the little river Lède for continuous work. An official report of 1811 described la Courrance as 'a foundry for cast iron' which had made only one cast since the Revolution, adding 'stagnation of the water shared with a corn mill, feeble flow'. In 1827 another report noted laconically, 'a blast furnace in the uttermost state of ruin, long since abandoned'.

Armed with this information I sought la Courrance. At first all seemed to be unpromising as the owners of the trout farm which is located at the former corn mill disclaimed any knowledge of any ironworks. Fortunately the smallholder who lives beside the trout farm, who had been called to aid the search, announced that the furnace was on his land.

He and his wife then showed me the site of the late 18th century blast furnace of which only part of the back wall survives. This is of good ashlar masonry for some 6 or 7 metres, flanked by rubble walls, all standing about 2 metres high. (Figure 2). As the area is so well drained he uses it for a chicken house and run, which limits the opportunity for inspection. In the adjacent cultivated field we found blue-green blast furnace slags and pieces of ore. I was assured that the next field, not cultivated, is likewise full of slags. This physical evidence agrees well with the documentary evidence for a short-lived blast furnace at the end of the 18th century.

The analyses of the samples were:(9)

1. Slags – Blast furnace

	a) a dense sage-green to blue slag;	b) a porous, cindery slag;
Fe0	2.9%	54.1
$Fe_2 0_3$	0.1	6.3
$Si0_2$	61.4	26.6
$Al_2 0_3$	7.4	3.9
Ca0	22.2	3.7
Mg0	0.9	0.2
Mn0	1.2	1.2
$P_2 0_5$	<0.2	0.3
S	not determined	not determined

2. Ore — Local hematite

FeO	0.3
Fe_2O_3	67.9
SiO_2	21.4
Al_2O_3	1.8
CaO	0.4
MgO	<0.2
MnO	0.9
P_2O_5	<0.2
S	not determined

Ratis[10]

The forge at Ratis seems to have been constructed at the end of the 17th century. It was a Catalan forge, and so, was independent of any blast furnace. A report of 1764 stated that Ratis furnished 400 quintals (ie. old quintals of 50 kilos each), or about 20 tonnes annually of bar iron for local sale. The forge worked for only six months of the year because of the shortage of water. There was also a complaint that wood had become so scarce, and the cost of living so high, that the production had been halved. Nothing else is known of Ratis during the 18th century except the names of a tenant and an owner.

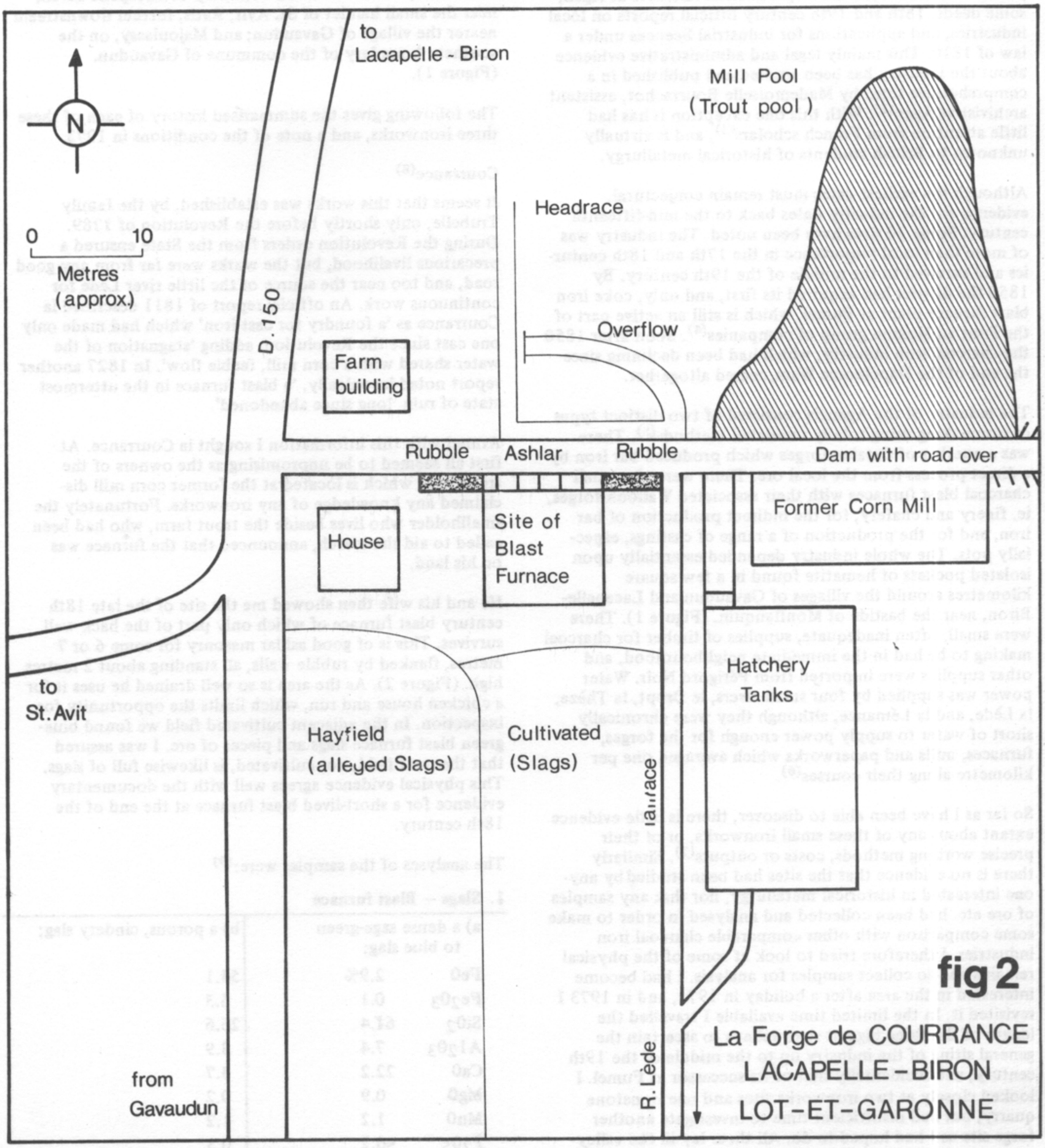

fig2

La Forge de COURRANCE
LACAPELLE – BIRON
LOT–ET–GARONNE

In 1813 another official report referred to the bar iron forge there. Still short of water, it could be used for seven or eight months of the year, and was let for 400-600 francs. In 1820, Jean Trubelle, the owner of this and numerous other local ironworks, applied for a licence to use his forges. He described Ratis as having 'one hearth for smelting ore in the manner practised in Ariège', ie. as a Catalan forge, with two hammers weighing respectively 12 and 5 old quintals (c. 600 and 250 kilos). The ore was obtained from the immediate neighbourhood, 'where it is found in kidneys in the sand and loose soil'. The fuel was oak and chestnut from local woodlands. The Royal Licence to operate, dated 5 March 1823, defined the works as a Catalan iron forge with two hammers of 6 and 3 metric quintals respectively (c. 600 and 300 kilos). The last mention was in 1828 when the new owner, Louis-Francois Petit-Lamazure, was asking for a licence to establish a blast furnace at Libos, near Fumel. He alleged then that he was trying to restart the forge at Ratis, where he was living, as well as its neighbour, la Courrance. As he died immediately afterwards it is unlikely that they were ever restarted.

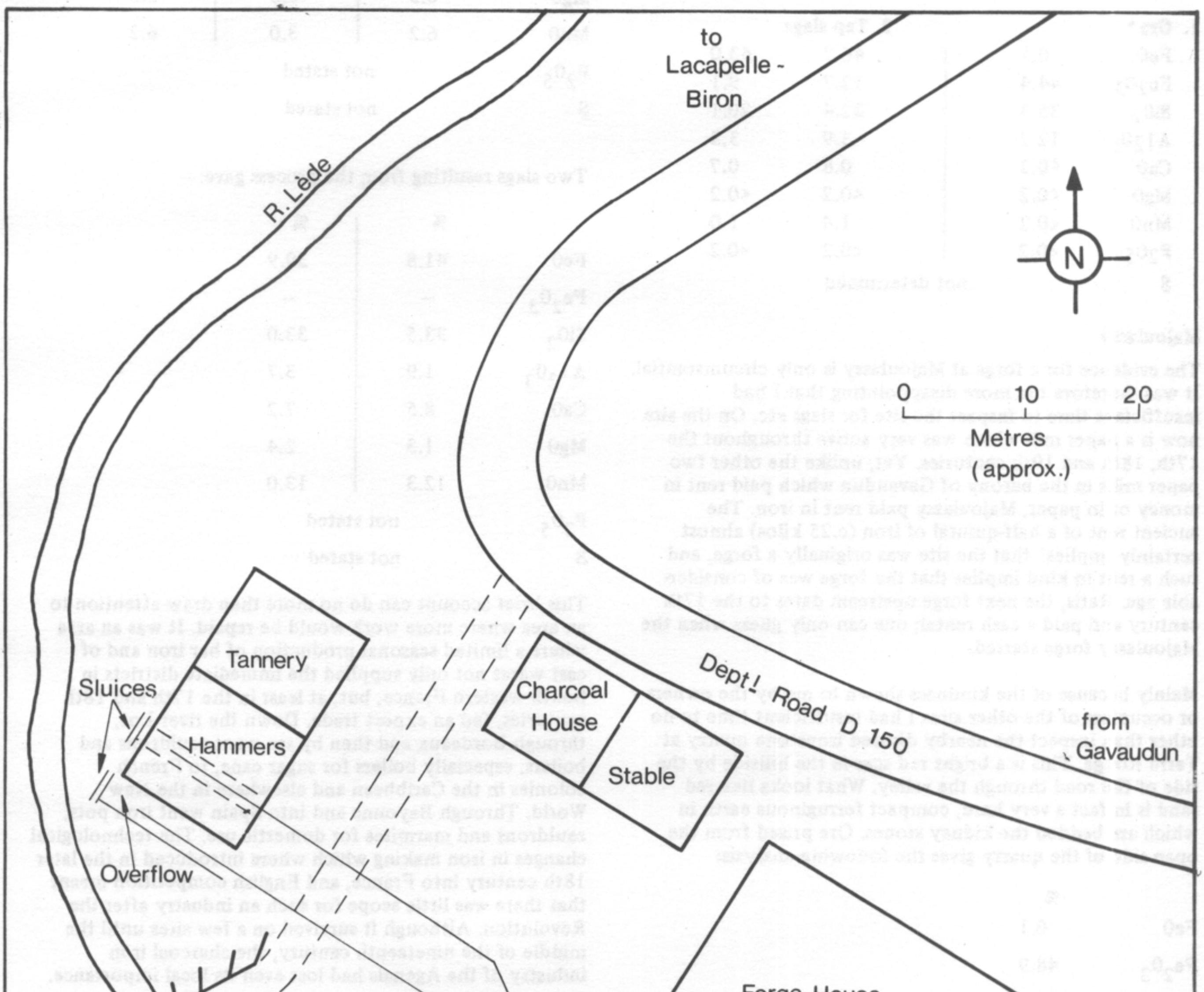

fig 3

La Forge de RATIS
GAVAUDUN
LOT-ET-GARONNE

La forge de Ratis (Les Forges as it now known) lies in a narrow part of the valley, downstream from Courrance. It lies well below road level and on the inside of a sharp bend in the river. (Figure 3). The owner, Monsieur E. Momnéjean, who is rebuilding the forgemaster's house of c. 1730, was most helpful and spent some time showing me the remains of the hammermill and charcoal house, and the later tannery which I presume was on the site of the Catalan furnace. There were a number of leats and sluices, but (as might be expected as it was August) rather lush undergrowth prevented close investigation.

The analyses (%) of slag and ore samples I took away are:

	1. Ore*	2. Tap slags	
FeO	0.1	46.7	63.0
Fe_2O_3	44.4	12.7	9.1
SiO_2	35.3	32.4	20.1
Al_2O_3	12.2	3.9	3.3
CaO	<0.2	0.8	0.7
MgO	<0.2	<0.2	<0.2
MnO	<0.2	1.4	1.0
P_2O_5	<0.2	<0.2	<0.2
S	not determined		

Majoulassy

The evidence for a forge at Majoulassy is only circumstantial. It was therefore the more disappointing that I had insufficient time to inspect the site for slags etc. On the site now is a paper mill which was very active throughout the 17th, 18th and 19th centuries. Yet, unlike the other two paper mills in the barony of Gavaudun which paid rent in money or in paper, Majoulassy paid rent in iron. The ancient rent of a half-quintal of iron (c.25 kilos) almost certainly implies that the site was originally a forge, and such a rent in kind implies that the forge was of considerable age. Ratis, the next forge upstream dates to the 17th century and paid a cash rental; one can only guess when the Majoulassy forge started.

Mainly because of the kindness shewn to me by the owners or occupiers of the other sites I had insufficient time to do other than inspect the nearby disused ironstone quarry at Terre Rouge. This is a bright red scar in the hillside by the side of the road through the valley. What looks like red sand is in fact a very hard, compact ferruginous earth in which are bedded the kidney stones. Ore prised from the open side of the quarry gives the following analysis:

	%
FeO	0.1
Fe_2O_3	48.9
SiO_2	37.0
Al_2O_3	5.1
CaO	<0.2
MgO	<0.2
MnO	<0.2
P_2O_5	<0.2
S	not determined

It is notable that neither the whole stones, from this quarry nor the fragments found at the sites has any appreciable manganese content. They may be compared with those quoted by Percy(12) for ores used in the mid-19th century for the Catalan process in the Pyrennees. Three manganiferous ores, apparently typical of the process in Ariège gave the following analyses:

	%	%	%
FeO	–	–	–
Fe_2O_3	62.5	65.5	64.0
SiO_2	14.7	11.4	10.5
Al_2O_3	1.0	1.3	1.2
CaO	2.8	5.0	3.5
MgO	0.5	0.5	0.8
MnO	6.2	3.0	6.2
P_2O_5	not stated		
S	not stated		

Two slags resulting from the process gave:–

	%	%
FeO	41.8	39.9
Fe_2O_3	–	–
SiO_2	33.5	33.0
Al_2O_3	1.9	3.7
CaO	8.5	7.2
MgO	1.3	2.4
MnO	12.3	13.0
P_2O_5	not stated	
S	not stated	

This brief account can do no more than draw attention to an area where more work would be repaid. It was an area where a limited seasonal production of bar iron and of cast wares not only supplied the immediate districts in South-western France, but, at least in the 17th and 18th centuries, fed an export trade. Down the river Lot, through Bordeaux and then by sea went cauldrons and boilers, especially boilers for sugar cane, to French colonies in the Caribbean and elsewhere in the New World. Through Bayonne and into Spain went iron pots, cauldrons and marmites for domestic use. The technological changes in iron making which where introduced in the later 18th century into France, and English competition meant that there was little scope for such an industry after the Revolution. Although it survived on a few sites until the middle of the nineteenth century, the charcoal iron industry of the Agenais had lost even its local importance.

ACKNOWLEDGMENTS

I am grateful to Charles,Blick for his good offices, and to Keith Reynolds, of Birmingham Polytechnic, who drew the illustrations from my working sketches.

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Steel from 100 years ago

K. C. Barraclough and J. A. Kerr*** ©

The Percy Collection, which is now in the custodianship of the Science Museum in Kensington, is an assemblage of over 4000 samples of metallurgical interest, collected together by Dr. John Percy, the eminent Victorian metallurgist who is probably best remembered as the author of a series of comprehensive treatises on the metal industries published between 1860 and 1870. His specimens whould appear to have been collected over about forty years; a catalogue was prepared in 1894 after his death and this makes fascinating reading in itself, since it contains a description of each and every item, with comments, together with the provenance and date. To the student of the history of technology there are obviously many samples which it would be most instructive to examine and compare them with modern materials. A report on two such samples (together with one from elsewhere) was published recently.(1) As a result of this examination, it was thought fit to probe further into the quality of crucible steel as made in the period 1860–1880, the period of its full development, and by courtesy of the Science Museum we have been priveleged to examine some thirteen samples of such material, together with what was thought to be likely to be a further sample of puddled steel (although this turned out to be wrought iron) and a sample of Brescian steel, which is of some interest as being ostensibly produced by one of the oldest described methods of steelmaking. The samples can be seen in Figure 1.

The crucible steels were found to fall into two distinct categories:

(A) Carbon steels: eight samples from four origins

(B) Tungsten steels: five samples from three origins. The presence of tungsten in two of these was, in point of fact, unexpected.

(A) CARBON STEELS

The catalogue entries for these specimens read as follows:

3506 Series of specimens of steel from the Dannemora Steelworks, Sheffield, 1879, communicated by Messrs Seebohm and Dieckstahl.

a) A round bar, labelled 2, of best warranted cast steel. Turning tool temper containing 1¼% carbon. The most useful temper for turning, planing and slotting tools, drills, small cutters and taps. It is not weldable. Has a granular fracture.

b) A flat bar with rounded sides, labelled 4. Best warranted cast steel. Chisel temper containing 1% carbon. Suitable for cold chisels, hot setts, large punches, large screwing dies, large taps and miners' drills for granite. Will weld with care. Fine grained with a hackly fracture.

c) A large octagonal bar, labelled 6. Best warranted cast steel. Die temper containing ¾% carbon. Suitable for boiler cups and snaps, hammers, stamping and pressing dies. Welding steel for plane irons, miners' drills, etc. A moderately coarse granular fracture.

3509 Samples of steel, manufactured by R. Mushet, 1866: they are made 'under the influence of titanium' and are granular in fracture.

a) Piece stamped 3, cast steel for turning tools and taps, made from one third common Swedish iron and two thirds Cumberland haematite pig iron.

b) Piece stamped 7, best file steel for saw files and other superior kinds. It is from common Bessemer scrap.

3518 Shaped and polished piece of Krupp's steel. From the Exhibition of 1862. It is broken across to show the fracture which is finely granular and hackly. Manufactured and fused at Essen.

3520 Bar of Krupp's steel. The outside has a silky fracture; in the inside it is coarser and granular.

3595 Piece of sheet steel after cutting out the blanks for steel pen making. From W. Jessops and Co. works, Brightside, Sheffield, 1885. It is returned from Birmingham to be remelted. (The sample was found to be 0.0105″ thick).

Small pieces were cut, as agreed with the Science Museum, from all samples and these were submitted to chemical analysis and metallographic examination. The following analyses were obtained:

	C	Si	Mn	S	P	Others *
3506–2	1.21	0.11	0.25	0.026	0.015	
3506–4	1.02	0.15	0.22	0.019	0.014	
3506–6	0.92	0.09	0.32	0.025	0.016	
3509–3	0.96	0.47	0.48	0.041	0.020	
3509–7	1.09	0.29	0.35	0.053	0.042	
3518	0.54	0.21	0.22	0.037	0.026	Cr 0.1%; Cu 0.2% approximately
3520	0.78	0.17	0.14	0.039	0.020	Cu 0.1% approximately

***All samples were checked spectrographically for chromium, nickel, molybdenum, copper, vanadium, titanium and tungsten; these were only detected in 'traces' except in the two Krupp samples. The absence of reported titanium in the two Mushet samples should be noted. Due to the nature of the pen-nib sheet sample, 3595, only carbon could be determined, giving a figure of 0.88%; other indications, however, were that it was a plain carbon steel.**

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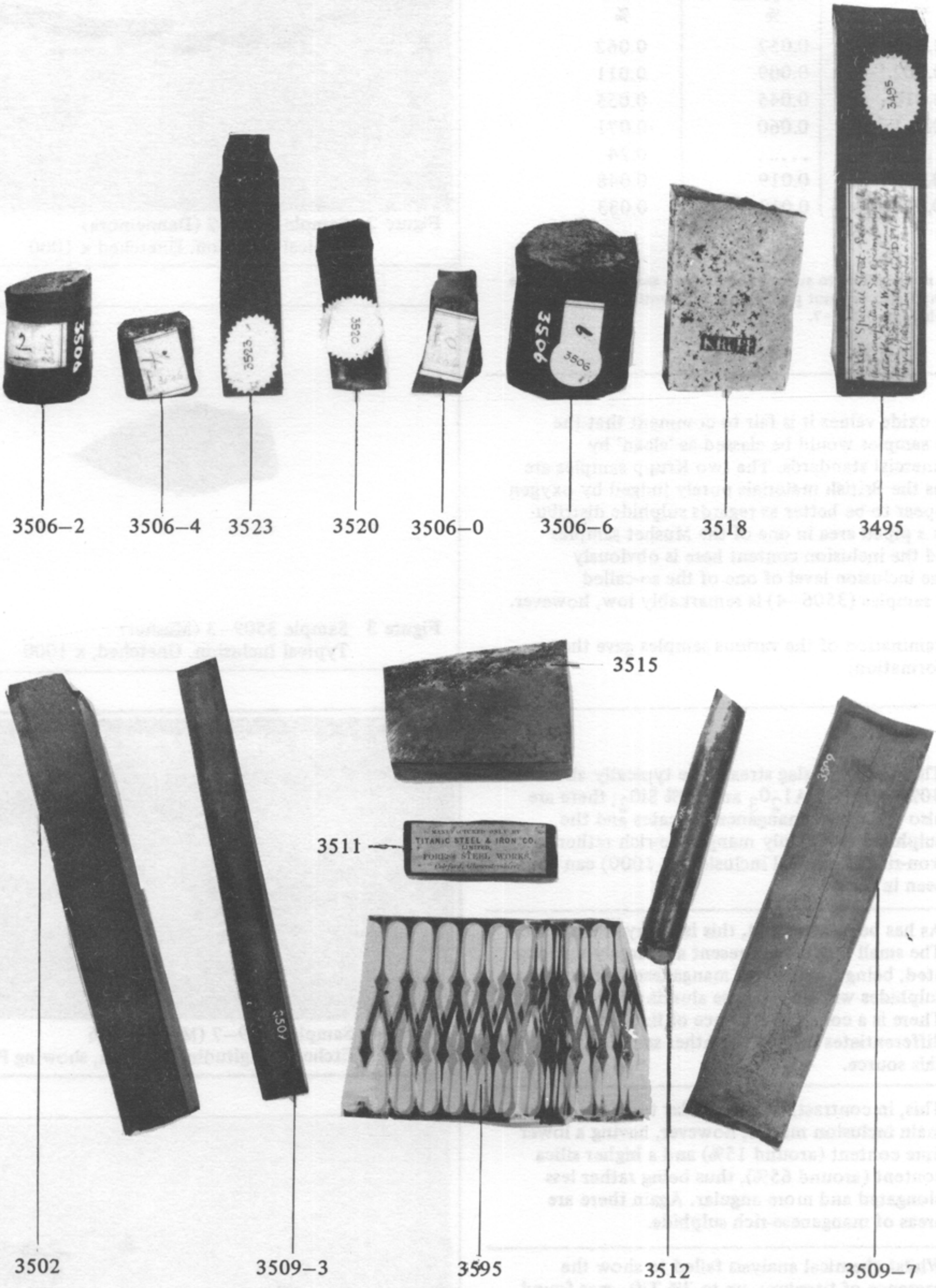

Figure 1 The Samples as received for examination

A cleanness assessment, based on area counts on both oxide and sulphide inclusions, gave the following information:

	Oxide %	**Sulphide** %	**Total** %
3506–2	0.010	0.052	0.062
3506–4	0.002	0.009	0.011
3506–6	0.010	0.045	0.055
3509–3	0.011	0.060	0.071
3509–7*	.....	.....	0.24
3518	0.029	0.019	0.048
3520	0.014	0.019	0.033

***Again, it was not possible to submit the pen nib sample to this type of examination; it also was not possible to differentiate between oxide and sulphide in 3509–7.**

Based on the oxide values it is fair to comment that the bulk of these samples would be classed as 'clean' by modern commercial standards. The two Krupp samples are not as good as the British materials purely judged by oxygen levels, but appear to be better as regards sulphide distribution. There is a piped area in one of the Mushet samples (3509–7) and the inclusion content here is obviously abnormal. The inclusion level of one of the so-called 'Dannemora' samples (3506–4) is remarkably low, however.

Individual examination of the various samples gave the following information:

3506–2 The elongated slag streaks are typically about 30% Ca0, 15% $A1_20_3$ and 50% $Si0_2$; there are also some pure manganese silicates and the sulphides are mainly manganese-rich rather than iron-rich. A typical inclusion (x 1000) can be seen in Figure 2.

3506–4 As has been remarked, this is a very clean steel. The small inclusions present are largely unelongated, being mixtures of manganese/iron sulphide sulphides with manganese aluminosilicates. There There is a complete absence of lime, which differentiates it from the other samples from this source.

3506–6 This, in contrast, is very similar to 3506–2, the main inclusion matter, however, having a lower lime content (around 15%) and a higher silica content (around 65%), thus being rather less elongated and more angular. Again there are areas of manganese-rich sulphide.

3509–3 Whilst chemical analysis failed to show the presence of titanium, up to 3% $Ti0_2$ was found in the inclusion matter in this sample as against around 0.3% in the three previous samples. There are some particles of almost pure silica and others of almost pure manganese sulphide; the main inclusion matter is, however, typically 63% $Si0_2$, 20% Mn0, 10% $A1_20_3$, 4% Ca0 and 3% $Ti0_2$. An inclusion of this type (x1000) is shown in Figure 3.

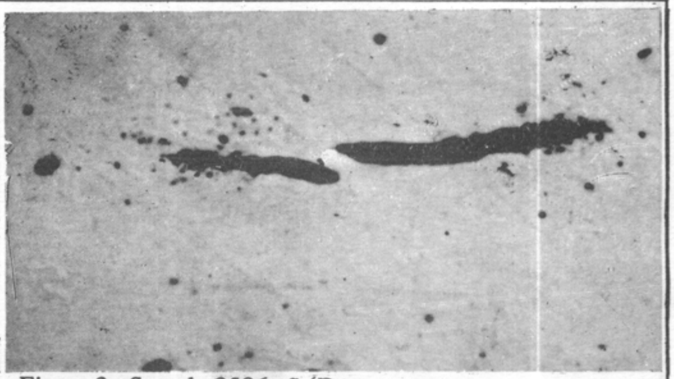

Figure 2 Sample 3506–2 (Dannemora)
Typical Inclusion. Unetched x 1000

Figure 3 Sample 3509–3 (Mushet)
Typical Inclusion. Unetched, x 1000

Figure 4 Sample 3509–7 (Mushet) x 6
Etched Longitudinal Section, showing Piped Area,

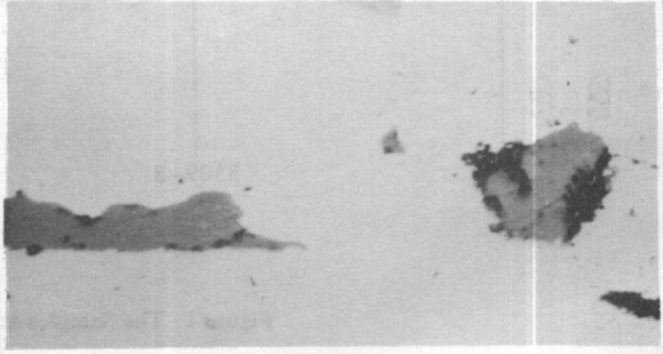

Figure 5 Sample 3518 (Krupp)
Typical Inclusion. Unetched, x 1000

3509–7	This is not a particularly good piece of steel. As can be seen from Figure 4 it is excessively piped, the central region carrying massive sulphides. Away from this area, there are stringers of titanium-rich silicates, one particular area registering as much as 23% $Ti0_2$, but with an average level of around 6%, the balance being 40–55% $Si0_2$, 7–15% $A1_20_3$, 18–36% Mn0 and some admixed MnS. Lime and magnesia are present only in traces.
3518	Here significantly, in a Krupp sample, we can also detect up to 3% $Ti0_2$. There are numerous sulphide inclusions. The silicate inclusions run high in silica (58–83%) with varying amounts of of alumina (4–16%) and manganese oxide (4–35%). Lime and magnesia are virtually absent. A typical example is seen in Figure 5.
3520	This shows a different inclusion pattern from the previous Krupp sample, being much more similar to the Seebohm and Dieckstahl 3506–6, with around 60–65% $Si0_2$, 10–15% Ca0, but with a lower alumina content (around 5%) and some magnesia (around 3%) with up to 20% Mn0, titania being present only in traces.
3595	This pen nib sheet sample proved very difficult to examine. Whilst reasonably clean, the microprobe results are extremely variable; there are manganese sulphide areas and silicate stringers, these latter considerably broken up by by the rolling to sheet. There is little lime or magnesia (up to 3% of each) and virtually no titania.

(B) TUNGSTEN STEELS

The catalogue entries for these five samples read as follows:

3495	Bar of 'Vickers Special' steel. Communicated by D. Watson, 1869, when the process of manufacture was a secret, the production of steel by Vickers' patent of 1839 being an earlier stage. See Percy's 'Metallurgy: Iron and Steel', p.776. (The label on the bar, in Dry Percy's own hand, reads: 'Vickers' Special Steel. Secret as to manufacture. See accompanying letter from David Watson (a former student of mine). The two chisels marked D.P. (Dr. Percy)* and WY4 (Whitworth)* are described in the same letter'. (*These two samples are Nos 3496 and 3497 as now catalogued).
3502	Bar of steel manufactured by the Titanic Steel and Iron Company, at the Forest Steelworks, Coleford, Gloucestershire. Excessively fine and conchoidal in the fracture.
3506	Series of specimens of steel from the Dannemora Steelworks, Sheffield, 1879. Communicated by Messrs Seebohm and Dieckstahl. They are as follows: a) A square bar labelled 0, of Special Dannemora cast steel. For turning and planing tools on hard material. It has a very fine silky conchoidal fracture. (The other samples, described earlier, then follow in the catalogue).
3511	Sample of R. Mushet's special steel for lathe and planing tools. Manufactured in 1872 by the Titanic Steel and Iron Company at the Forest Steelworks, Coleford, Gloucestershire. Communicated by R. Mushet. The fracture is microscopically fine, is conchoidal and has a silky lustre. The steel requires only to be cold hammered and not tempered in the ordinary way.
3512	Small round bar of R. Mushet's special tool steel. The sample is as used without hardening. 1873.

The Science Museum permitted small samples to be cut from all specimens except 3511, which they requested should only be non-destructively examined, since it was an exhibition sample with the original label still attached. A spectrographic check indicated it to be very similar to sample 3512 in composition. Chemical analysis (%) of the remainder gave the following indications:

	C	Si	Mn	S	P	W	Sn
3495	0.62	0.28	0.24	0.060	0.029	2.64	0.13
3502	1.06	0.47	1.06	0.063	0.042	8.58	0.60
3506–0	1.27	0.16	0.25	0.019	0.055	3.08	pres.
3512	>1.20	0.55	1.25	–	0.031	8.27	pres.

In addition, spectrographic analysis indicated the presence of approximately 0.1% molybdenum in all four samples, with nickel, chromium, copper, vanadium and titanium present in not more than traces.

A cleanness assessment,based on area counts, gave the following indications:

	Oxide %	Sulphide %	Total %
3495	0.048	0.004	0.052
3502	0.002	0.110	0.112
3506–0	0.002	0.050	0.054
3512	0.005	0.089	0.094

Three of these steels are, therefore, remarkably low in oxide content; the sulphide levels, however, are high and, as will be seen from the photomicrographs (x 100, unetched) shown in Figures 6 to 9, the two Mushet samples show up rather badly.

Individual examination of the various samples leads to the following reports:

3495	There are some manganese sulphides present but the main silicate inclusion matter approximates to 80% $Si0_2$, 10% $A1_20_3$, 5% Mn0 and 2% $Ti0_2$, with a little lime and no magnesia. A typical inclusion, (X 1000) is shown in Figure 10.
3502	The inclusion matter here is virtually entirely sulphide.
3506–0	The silicate inclusion matter here is almost identical with that found in the carbon steel 3506–2 from the same works, with 25–30% Ca0, 15% $A1_20_3$ and 50% $Si0_2$. Titania is present in small quantity (around 0.5%) with 2–3% Mg0.

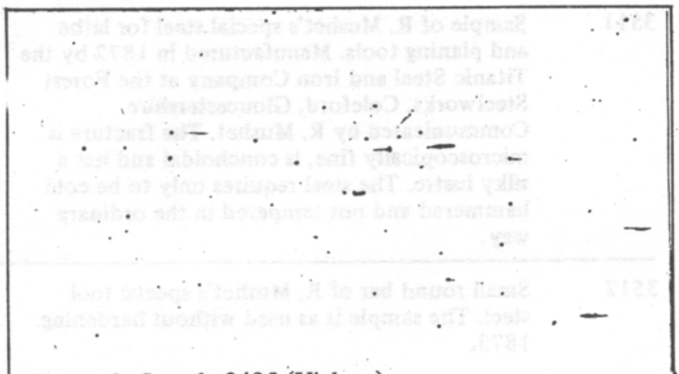

Figure 6 Sample 3495 (Vickers)
Unetched, x 100

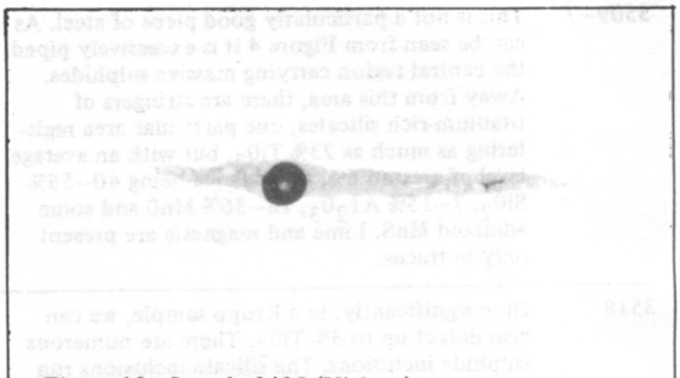

Figure 10 Sample 3495 (Vickers)
Typical Inclusion. Unetched, x 1000

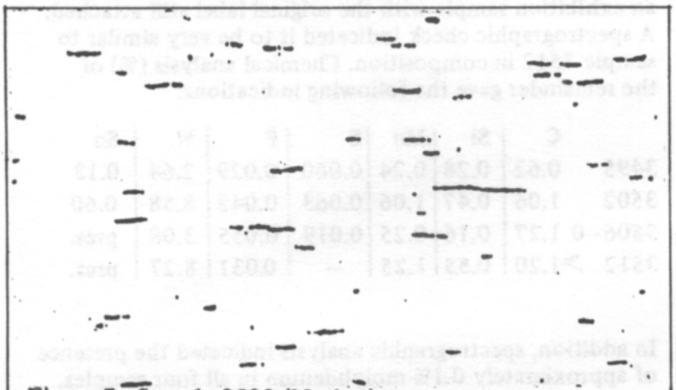

Figure 7 Sample 3502 (Mushet)
Unetched, x 100

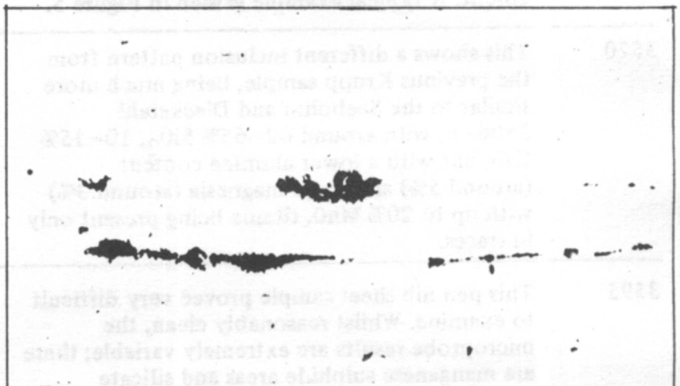

Figure 11 Sample 3512 (Mushet)
Typical Inclusions, Unetched, x 1000

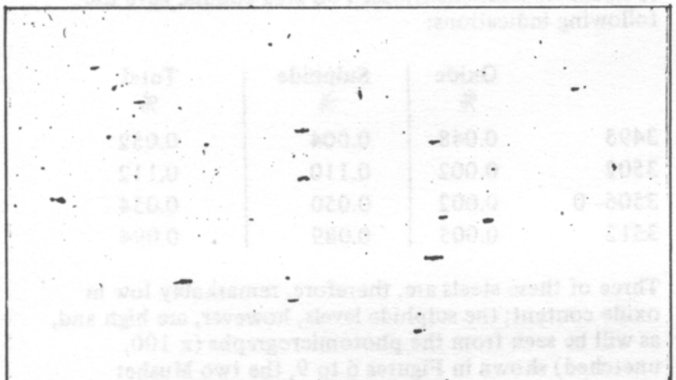

Figure 8 Sample 3506–0 (Dannemora)
Unetched, x 100

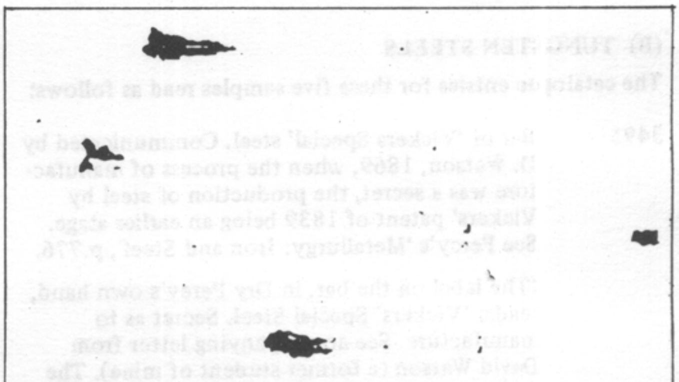

Figure 12 Sample 3511 (Mushet)
Typical Inclusions. Unetched, x 1000

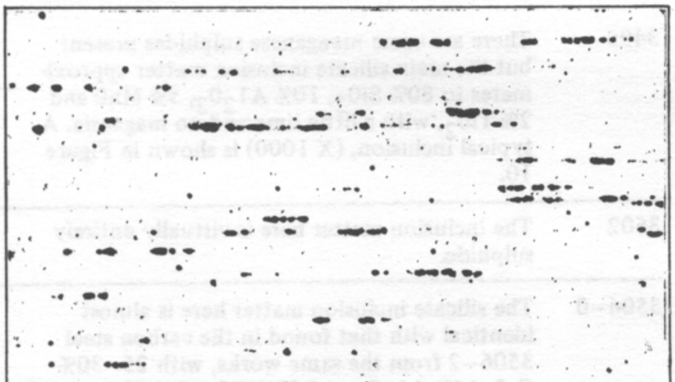

Figure 9 Sample 3512 (Mushet)
Unetched, x 100

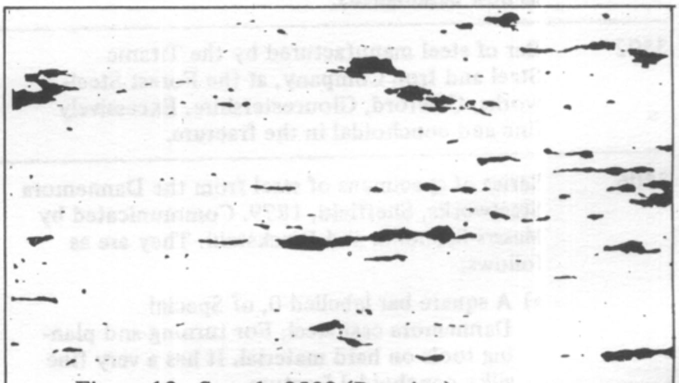

Figure 13 Sample 3523 (Brescian)
Unetched, x 100

3512 The silicate inclusions show 70–80% SiO_2 with 7–8% Al_2O_3 and 6–12% MnO, with less than 1% CaO plus MgO. Such an inclusion is difficult to deform, as will be seen from Figure 11; Figure 12 shows a similar pattern from the polished end of the bar from 3511, which could not otherwise be assessed. The numerous sulphides present were mainly manganese-rich. There is no evidence for titanium treatment of either this sample or the other Mushet item (3502).

In view of the fact that the Mushet steels were supposedly in the state in which they were to be used, it was considered of interest to determine the hardness of these four samples, with the following results:

	Hardness HV/30
3495	283, 292, 294
3502	446, 467, 476, 478
3506–0	314, 318, 329, 334
3512	462, 467, 470

(C) LOW MOOR 'STEEL'

The catalogue entry reads:

3515 Sample of steel from the Low Moor Iron Works. Of large size and having a rough coarse fracture.

This sample was considered to be of possible interest since it conceivably was puddled steel, the first recorded indication of the production of such a material in this country being at this particular works. Analysis, however, indicated it to be wrought iron rather than steel:

C	Si	Mn	S	P	Ni	Cr	Mo	Cu	Ti	V
0.072	0.10	0.03	0.002	0.073	Present in traces only.					

The structure is mainly ferritic with entrained slaggy areas; there is a little pearlite in the grain boundaries. The slaggy matrix is some 68–72% Fe_2O_3 with 1–2% MnO, 20–22% SiO_2 and around 3% P_2O_5, typical of 'puddling cinder'. With an oxide area count of 3.8% it indeed ranks as a rather inferior example of 'Best Yorkshire Iron'., There is, however, a second sample under the same catalogue number which could be worth at least a cursory examination.

(D) BRESCIAN STEEL

Here the catalogue entry reads:

3523 Oblong bar of Brescian steel. From the International Exhibition, 1862. Communicated by the Italian Department. It has a finely granulated fracture and has been forged down at one end.

Brescian steel was described by Vannoccio Biringuccio about 1550 and later by Reaumur; thin bars of wrought iron were immersed for a short period of time in a molten bath of cast iron and then withdrawn, a number then being made together into a 'faggot' and forge welded together; about 1850 this process was also in use in one or two places in Austria (Styria) and the product was known as 'Paal' steel. It was, in effect, an accelerated cementation process. It was felt, therefore, that the product should be akin both to puddled steel and shear steel, but in either case would show the entrained slag from the original wrought iron.

The sample gave the following analysis:

C	Si	Mn	S	P	Ni	Cr	Cu	Mo	Ti	V
0.96	0.02	0.08	0.005	0.010	Present only in traces					

It was thus the purest sample examined with regard to sulphur and phosphorus contents. As expected, however, the slag content was high, giving an area count of 0.83% but with no sulphide. Figure 13 shows a typical section (unetched, x 100).

GENERAL COMMENTS

The original intention of this exercise was to endeavour to check the general cleanness levels of crucible cast steel, since the sample from the Percy Collection previously examined had proved to be remarkably free from inclusion matter, although it must be admitted that it was not an example of regular crucible steel production but an experimental melt set up for the information of Dr Percy himself.

The first surprise, however, was to find that three samples, in addition to the two examples of Mushet 'Special', contained tungsten. Admittedly one of these three was contributed by Mushet himself and could conceivably have been from his earlier experimental work, but the catalogue gives no indication of anything unusual about it

A second sample was from 1879, when Mushet's 'Special' was already being made in Sheffield; again although referred to as 'Special Dannemora Cast Steel', there is nothing in the catalogue entry to classify it as an alloy steel. The third sample, of 'Vickers Special'; is from 1869 and is said to be of secret manufacture; the reference in the catalogue to Vickers Patent of 1839 does not seem to have much relevance other than in general terms, since this was concerned with the melting together of wrought iron and white cast iron in the crucible, together with some manganese. Certainly, this was becoming the general practice in Sheffield in 1869, thus obviating the need for the cementation process (the Vickers River Don Works having been built a few years earlier without any cementation furnaces to feed the 384 double-crucible holes) but the tungsten addition was not to be expected. Mushet's first tungsten patents were filed in 1859 but he does not seem to have produced commercial material until 1868(2).

This sample from a competitor in 1869 would appear, probably, to be a patent infringement: no wonder its method of manufacture was secret! On the other hand, it is significant that the two Mushet samples are much higher in manganese than the two competitors' steels: Mushet appears to have produced his materials by reacting cast irons with wolframite in the crucible, this ore being essentially an iron-manganese tungstate. The other two manufacturers may have used a different ore or even a prereduced tungsten alloy. The inclusion matter in the Vickers sample is, however, surprisingly similar to that in one of the Mushet samples, whilst the Dannemora sample shows the same inclusion pattern as in one of the carbon steels from the same source, with a significant lime content which could possibly indicate the use of scheelite instead of wolframite as the source of tungsten. All the tungsten steels submitted to chemical analysis show the presence of fair amounts of tin, against presumably derived from the ore. One would, however, look askance at a high speed steel to-day with 0.6% of this element present; if this is, however, typical of the 'Mushet Special' then it performed its task very well in spite of this. The Mushet samples also are high in sulphur (and this applies to the carbon steels from Coleford as well); one point to be noticed is that whilst the sulphur content of the Dannemora steel is low, in common with the carbon steels from this source, indicating the use of high quality melting base, the phosphorus content of the tungsten steel is abnormally higher than that of the carbon steels, presumably from the tungsten source. The absence of chromium should be noted in the Mushet samples; although sample 3512 is dated 1873 in the catalogue, it would seem to be of earlier date if the information given elsewhere is correct(3), since, by that time, Mushet seems to have increased his carbon content to over 2%, reduced the tungsten to about 6% and introduced up to 1% of chromium. Mushet, it should be noted, is using 'substitute' materials in this crucibles;one must appreciate the subtlety of the description 'best file steel for saw files and other superior kinds' for a steel produced from common Bessemer scrap, especially bearing in mind his own personal attitude to Bessemer!

The grading of carbon steels into 'tempers' by assessment of the fracture of the forged bar was standard practice in Sheffield and the entries in the Percy catalogue with reference to the Dannemora steels produced by Seebohm and Dieckstahl obviously come from the manfacturers' own list. All Sheffield firms had hese; some, like Huntsman, put different coloured labels on their various grades; others, like Firths had Warranted, Extra, Double Extra and Treble Extra for the increasing carbon contents or tempers. The Dannemora steels seem to have had the lowest number for the highest carbon; generally the reverse was true with those who used a number scale, razor temper generally being '7'. It has often been remarked how accurate an estimate of carbon content could be obtained from the fracture and here we have three examples, one of them being somewhat out it must be confessed:

Sample	Temper	Carbon Content Listed	Carbon Content Actual
3506–2	Turning Tool	1¼%	1.21%
3506–4	Chisel	1%	1.02%
3506–6	Die	¾%	0.92%

It is, indeed, doubtful whether such materials would be submitted to chemical analysis other than for special purposes; it must be remembered that each melt was only about 50 lb. average weight and at least 10,000 such melts must have been made in Sheffield every day around 1870!

With regard to cleanness, most of these samples would be downgraded on sulphide contents; even so, they are acceptable by modern standards, with the possible exception of the Mushet steels which have relatively low oxide contents, indicating adequate deoxidation technique but, with sulphur contents in excess of 0.04%, cannot hope to be classed as clean steels. The Dannemora steels, on the other hand, which must be taken as being more typical of normal Sheffield practice, with sulphur contents around 0.02%, are good clean materials; one of them, the 1% carbon steel 3506–4, being of the same high order of cleanness as the Firth sample previously examined.

The inclusion type is interesting; the exceptionally clean Dannemora steel shows no lime content, whilst the other three from this source have significant lime contents, up to 30% in one case. The Krupp steels are of similar cleanness to these last three and one of these, 3520, has a very similar inclusion type. The other Krupp sample shows no lime and an inclusion type very similar to that of the Vickers 'Special' sample, 3495. Both these, in addition, contain around 3% of titanium dioxide in their inclusions. The two Mushet steels 'made under the influence of titanium', whilst evidencing no metallic titanium, show significant amounts of this oxide in their inclusions, from 3% to 23%, although the average values seem to be about 3% and 6% respectively. All other samples give less than 1% titanium dioxide in any inclusions. It would seem, therefore, that both Vickers and Krupp took notice of the numerous Mushet patents and felt some benefit could be obtained in this way; it should be noted that Mushet himself did not appear to combine the tungsten and titanium treatments whilst it could be postulated that Vickers did. Further, does this point to Vickers using a different technique for tungsten additions, taking into consideration the lower carbon and manganese content of such a steel compared with Mushet's? It is also of interest that the 'Dannemora Special' has a very similar content of tungsten to the 'Vickers Special', much lower than in the Mushet steels. The Vickers and Dannemora steels have different carbon contents but are not very different in hardness and are considerably softer than the Mushet samples.

The two remaining samples examined fall into a completely different category. As has been remarked, the Low Moor sample was wrongly classified; the Brescian steel, as expected, turned out to be very little different from the sample of puddled steel examined earlier(1) in its character, with almost identical slag content. It is, however, remarkable for its purity as regard sulphur and phosphorus, being better than most Swedish materials and it would be of interest to know of the origin of the raw material used.

The only other comment which is required is to remark on the beautiful polished finish on Krupp sample 3518 (now slightly pitted).

REFERENCES

1 K. C. Barraclough and J. Kerr: 'Metallographic Examination of Some Archive Samples of Steel', JISI 1973, 211 470–474.

2 F. M. Osborn. 'The Story of the Mushets', 1951, pp 71–77.

3 F. M. Osborn. loc. cit., pp 90–91.

ACKNOWLEDGMENTS

The authors wish to place on record their thanks to Mr. L. R. Day of the Science Museum for loan of the various samples and the permission to remove portions from most of them for this examination to be carried out. Their thanks are also due to the Directors of Firth Brown Limited and, in particular, to Dr. H. W. Kirkby for the facilities provided at the Brown Firth Research Laboratories. They also acknowledge the assistance of the Firth Brown Photographic Department in the production of the illustrations.

Analyses of Wealden iron ores

B C Worssam and J Gibson-Hill ©

1 INTRODUCTION

In 1973, as a result of continuing rescue excavation of the Iron Age and Romano-British industrial settlement at Broadfields(1), near Crawley, and of the study of temporary excavations for foundation works for the expanding New Town, ironstone samples were obtained of a clearer archaeological significance than those reported on in an earlier study(2) of iron ore workings of the Horsham-Crawley area. Three samples, from differing geological horizons, were submitted to the Petrographical Department, Institute of Geological Sciences, for analysis by the Laboratory of the Government Chemist. The resulting analyses are given in Table 1.

Complete analyses were requested because from the metallurgical point of view some constituents present in only minor proportion can exert a significant influence on the smelting process. Also, a knowledge of the complete composition of typical ores, including elements present in trace quantity, may help in identifying ore from analyses of slags.

As far as the authors are aware, only six analyses of iron ores from the Weald have previously been made. These are listed in Table 2, and in this paper their salient features are compared with those of the new analyses. The archaeological significance of the new analyses is discussed in a separate paper.(3)

2 IRON ORES FROM THE VICINITY OF CRAWLEY

Localities mentioned in description of the samples from near Crawley are to be found on the one-inch to one mile geological map, Sheet 302 (Horsham), and on six-inch geological map sheets TQ 23 NW and SW.

2a Silty siderite mudstone, Upper Tunbridge Wells Sand *(Lab. No 2488)*

In July 1973 a sewer trench in the Broadfield Forest south of Crawley crossed the nearly continuous belt of minepits(2) that runs east-west for 4 km from Silver Hill [235 340](4) almost to Tilgate [275 345]. Mapping shows that the belt lies on the outcrop of a clay member of the Upper Tunbridge Wells Sand, in a 'slack' or slight hollow between two ridges, one formed by the Colgate Sandstone to the south and the other by the Roffey Park Sandstone to the north. Before the sewer trench was dug there was no evidence for the nature or precise position of the ore seams worked in the pits. For most of its length the trench was already backfilled when first visited. Ironstone fragments were however rare in the excavated debris except in the vicinity of the belt of pits. The trench was there [2598 3443] open over a distance of about 20m and to a depth of 2 to 3m, and exposed about 6m of strata as follows, dipping at 6° NNW:

	m
8. Silty clay, weathered, light grey	1.5
7. Silty siderite mudstone (Lab. No 2488)	0.08 – 0.16
6. Shaly clay, dark grey, with thin (3cm) layers of fine-grained clay ironstone at 20–30cm intervals; a lens of clay ironstone up to 18cm thick and 2m in extent occurs at the top of the bed at one place	1.2
5. Silty clay, grey, roughly laminated	0.5
4. Sandstone, grey, silty, hard	0.6
3. Mudstone, medium dark grey, slightly silty, laminated	0.6
2. Siltstone, dark grey, laminated	0.6
1. Sandstone, medium grey, silty, laminated, hard, seen for	1.0

Beds 1 to 4 represent with little doubt the upper part of the Colgate Sandstone. The thin layers and occasional large masses of clay ironstone in bed 6 may have been utilised for ore, but bed 7, being the thickest and most persistent ironstone seam in the section, and bulking most largely in the material excavated from the trench, is believed to have been the main iron-ore horizon.

Bed 7 is a hard, dense rock that weathers to limonite (ferric oxide) along joint surfaces, producing ferruginous 'box stones'. The sample analysed was of grey, unweathered rock from the centre of such a box-stone. In thin section (E43614)(5) it is seen to consist of angular quartz grains, mostly between 0.1 and 0.3mm diameter, interspersed with smaller grains (down to 0.003mm), and fine-grained carbonate allochems, in a matrix of minute rhomb-shaped siderite (ferrous carbonate) crystals of 0.001mm diameter. The edges of some quartz grains appear to be corroded, which suggests partial replacement of quartz by siderite. As well as quartz, grains of metamorphic quartzite are fairly numerous. Detrital grains present in very minor amounts include quartz-mica schist, microcline, felsite, muscovite and, possibly, chert (determinations by Mr R.W. Sanderson). Heavy detrital minerals include tourmaline, zircon, garnet, and granules of TiO_2-polymorphs. There are scattered specks of opaque iron oxide.

The analysis (Table 1, col. 1) shows the content of iron oxides to be about 40% by weight. This is low for an iron ore and the silica content (22%) is high. The ratio of FeO to CO_2 in ferrous carbonate is about 48 to 30. The 37% of FeO in the sample may therefore have been combined with 23% CO_2 and the remaining CO_2 (2.5%) with magnesium and calcium oxides. It was formerly presumed(2) that the minepits were dug to supply blast furnaces in St Leonards Forest area, operating in the 16th and 17th centuries. However, a section in an open part of the sewer trench [2594 3451] showed bloomery slag, apparently the infill of an old excavation, to a depth of 2m below ground surface. This slag, if the product of bloomery furnaces in its immediate vicinity, may imply pre-16th century working of iron ore in the forest.

2b. Roasted clay ironstone *(Lab. No 2490)*

This iron ore when discovered on the Broadfields bloomery site was covered by the broken remains of a smelting furnace, dating from the second century AD. Its proximity to the furnace suggests that it originally formed part of the burden but was not required.(3) The sample occurred in the

TABLE 1

Analyses of iron ores from the Crawley district

	1 Lab. No 2488 %	2 Lab. No 2489 %	3 Lab. No 2490 %
$Si0_2$	22.43	23.96	8.52
Al_20_3	4.64	9.56	5.54
Fe_20_3	1.52	39.73	73.80
Fe0	37.10	n.d.	n.d.
Mg0	1.13	0.52	1.86
Ca0	1.38	0.30	1.80
Na_20	0.11	0.11	0.04
K_20	0.71	1.16	0.44
$H_20 > 105^o$	2.19	8.86	1.13
$H_20 < 105^o$	0.54	6.04	0.73
$Ti0_2$	0.36	0.55	0.35
P_20_5	0.32	0.48	0.75
Mn_30_4	n.d	n.d	4.55
$Mn0_2$	n.d	7.21	n.d.
Mn0	1.86	n.d.	n.d.
$C0_2$	25.50	0.97	0.12
Allow for minor constituents	0.11	0.35	0.10
	99.90	99.80	99.73

	mg/kg	mg/kg	mg/kg
Ba^+	370	1780	120
Co^+	<10	72	<10
Cr^+	20	54	26
Cu^+	14	39	15
Ga^+	<10	<10	31
Li	11	22	15
Ni^+	<10	100	<10
Rb	37	70	24
Sr^+	53	66	41
V^+	<10	72	46
Zr^+	170	210	170
B	32	39	22
F	150	350	420
S	190	280	110

n.d. Constituent not detected

\+ Spectrographic determination

Analyses by the Laboratory of the Government Chemist, analyst J. M. Murphy, J. I. Read and W. A. McNally. Spectrographic work by R. G. Burns. 19 July 1974.

2488	Silty siderite mudstone; bed 8 to 16cm thick in Upper Tunbridge Wells Sand. Temporary exposure in trench, 1.85km SSW of Crawley Station, Sussex [TQ 2598 3443]. Slice No E43614. (Ann. Rep. Inst. Geol. Sci. for 1974, 1975, p. 132).
2489	Iron pan: loose fragment on field surface on Weald Clay ironstone outcrop, 1.2km E of Upper Prestwood Farm. Charlwood. [TQ 247 397]. Slice No E4315.
2490	Roasted clay ironstone, from Broadfields bloomery, Furnace 607, 650m at 332° from Broadfield House [TQ 2603 3515]. Slice No E43616.

TABLE 2

Previous Wealden iron ore analyses

	1 %	2 %	3 %	4 %	5 %	6 %
$Si0_2$	26.10	6.46	4.13	9.49	10.3	60.75
Al_20_3	8.24	2.64	4.67	6.90	1.1	12.07
Fe_20_3	10.10	6.85	5.41	2.49	28.1	17.18
Fe0	30.42	42.08	48.09	39.52	25.4	n.d.
Mg0	0.25	1.76	0.18	0.25	2.0	0.10
Ca0	0.86	3.87	3.80	5.20	3.3	0.47
$H_20 > 105^oC$	1.11	tr	1.50	2.00	–	4.95
$H_20 < 105^oC$	0.18	0.15	0.39	0.53	–	0.23
$Ti0_2$	0.60	0.21	0.10	0.23	0.2	0.62
P_20_5	0.49	0.65	n.d.	n.d.	1.0	0.15
Mn0	1.29	2.32	0.46	0.71	1.6	3.30
$C0_2$	20.25	32.70	29.50	31.82	–	n.d.
B	–	–	n.d.	n.d.	–	–
$S0_3$	0.06	0.20	n.d.	n.d.	n.d.	0.18
FeS_2	0.05	0.11	–	–	–	n.d.
Ni	n.d.	n.d.	–	–	–	n.d.
Co	n,d.	n.d.	–	–	–	n.d
Cu	n.d.	n.d.	–	–	–	n.d.
Pb	n.d.	n.d.	–	–	–	n.d.
Zn	n.d.	n.d.	–	–	–	n.d.
C	–	–	1.71	0.92	–	–
As	tr	tr	–	–	–	tr
Loss on ignition	–	–	–	–	27.0	–
Total	100.0	100.0	99.94	100.06	100.0	100.0

n.d. constituent sought but not detected

– constituent not sought

tr trace

1 Ironstone from Ashdown Beds, Shape Wood. 1-inch geological map, Sheet 303 (634301). Anal. Tatlock and Thomson, Glasgow (ref. 18).

2 Clay ironstone, Wadhurst Clay, Giffords Farm, near Ashburnham. 1-inch Sheet 320 (690188). Anal. Tatlock and Thomson (ref. 18).

3 Clay ironstone, Wadhurst Clay, stream section near S. end of Crowhurst Park. 1-inch Sheet 320 (probably about 771122). Anal. T.V.M. Rao, Imperial College London (Ref. 25).

4 Clay ironstone, Wadhurst Clay, Rackwell Wood Quarry Crowhurst. 1-inch Sheet 320 (764123). Anal. T.V.M. Rao (ref. 25).

5 Clay ironstone, Wadhurst Clay, Sharpthorne brickworks, near West Hoathly. 1-inch Sheet 302 (373329). Anal. BISRA/IGL Teesside Laboratory (ref. 7). 'Total Fe' of the published analysis recalculated as Fe_20_3 for this table.

6 'Ragstone' on Wadhurst Clay or Ashdown Beds, N. margin of Snape Wood. 1-inch Sheet 303 (633307). Anal. Tatlock and Thomson (ref. 18).

form of cuboidal fragments, measuring about 3cm along the cube edges. The fragments are of a deep reddish purple colour and have a powdery coating that readily imparts a reddish-brown stain to one's fingers when they are handled. The thin section (E43616) shows an extremely fine-grained rock, opaque to plane polarised light except for rare angular quartz grains (0.1mm) and for numerous light specks some of which are birefringent and may be clay mineral flakes while others may be pores produced by roasting. In the roasting process(6,7,8) iron ores were heated in oxidising conditions when water and (from carbonate ores) carbon dioxide were expelled. The latter reaction is indicated by thermo-gravimetric analyses (TGA) to take place in the range 500-550°C with Coal Measures siderite.(9) Cleere(7,8) used Wadhurst Clay ironstone. He found that lumps of this tended to break up explosively when roasted; this facilitated their later breaking to the desired size for the furnace charge. The general appearance of the ore fragments in the Broadfields sample suggests that they were originally a fine-grained clay ironstone. It is probable that they came from the infra-Horsham Stone horizon.(10) A belt of mine-pits following this horizon narrows as it passes close to the furnace site, thus suggesting contemporaneity, although there is no direct evidence that the pits are of Romano-British date.

The analysis (Table 1, col 3) indicates an efficiently roasted, ore, with siderite almost completely converted to hematite by the expulsion of carbon dioxide. Because manganese goes into the slag in the bloomery process in preference to iron, and thus in a sense acts as a flux, Tylecote(11) suggested that in comparing analyses iron and manganese oxides should be considered together. The manganese oxide content of this ore is high, and added to the ferric oxide content gives the high figure of 78.35%. The small amount of calcium oxide present is also likely to have assisted fluxing.

2c. Weathered, recemented clay ironstone *(Lab. No 2489)*

At outcrop, clay ironstone weathers to limonite within 2m or so of the ground surface, and disintegrates into small fragments commonly about 10mm in diameter. Locally, owing to solution and redeposition resulting from a seasonally fluctuating water table, the fragmented material is cemented into hard lumps. The object of the third analysis was to show if the iron content of such cemented material is high enough for it to have ranked as an ore.

The sample is from a lump measuring about 20 x 10cm diameter, found [at 247 397] on the surface of a ploughed field, about 4km NW of Crawley and on the outcrop of a clay ironstone bed believed to be at the infra-Horsham Stone horizon. The specimen was found by Mrs Jean Shelley, of Crawley Local History Society, and is a random sample in that it was not deliberately selected from a geological point of view. Similar material is not uncommon in the soil at the site, and nearby, at the site [249 403] of the newly recorded Pit Croft bloomery(3), where bloomery slag occurs in the soil in association with Medieval pottery, are some slight depressions of the ground surface which could possibly be relics of shallow excavations for ore.

Analysis (Table 1, col. 2) shows that this rock, like Lab. No 2490, has a high manganese oxide content. This added to the ferric oxide gives a combined percentage of 47%, which is higher than the iron oxide + manganese oxide content of Lab. No 2488. The water content is higher than that of both other analyses, and were this water driven off by roasting, material that might have served as an ore would result, though high in silica and alumina. In thin section (E 43615) in the interstices between fragments of limonitised mudstone, are scattered detrital quartz grains up to 0.1mm in diameter in a minutely crystalline, ironstained matrix probably of weathered clay. Similar material but with coarser quartz grains (E 47166) occurs on the outcrop of the infra-Horsham Stone ironstone near Bewbush [at 2465 3563]. The angular ferruginous fragments here consist mainly of goethite (identified by X-ray diffraction powder photographs X 7356-7, by Mr R J Merriman) with some quartz. Amorphous iron oxide may also be present.

Iron pan of this nature is not uncommon on the outcrop of the Wealden Beds. It is given local names such as shrave, chevick, crowstone and ragstone. There is a tradition of its former use as an iron ore(12,13,14). The material analysed, in that it consists of limonite fragements concentrated in the soil above an ironstone outcrop, is probably more iron-rich than most. Another common type is formed by the cementation of river-gravels, but the presence of sandstone pebbles and, in the westernmost part of the Weald, chert pebbles in the gravels may give so high a silica percentage as to render such material of little value as an ore(15).

3 PREVIOUS ANALYSES OF WEALDEN IRON ORES

Apart from the three described above, only six complete analyses of iron ores from the Weald have hitherto been made. They are shown in Table 2, five of the samples being sideritic ironstones from the Hastings Beds and the sixth an iron pan. Excluded from consideration are two analyses of clay ironstone and sphaerosiderite from the lower part of the Ashdown Beds ('Fairlight Clays') near Hastings(16) and two of ferruginous sands from the Lower Greensand(17), for ironstone from these horizons is unlikely to have been dug on any significant scale and cannot therefore be regarded as an ore.

Three of the analyses in Table 2 were made by Gregory(18) who, commissioned to report to the Earl of Sheffield on the prospects of establishing an iron mining and smelting industry at Sheffield Park [413 242], sought first to determine the quality of Wealden ores at places where they had last been worked, namely Snape Wood near Wadhurst and the vicinity of Ashburnham, near Battle, where the last Wealden furnace closed down in 1810. He also analysed a sample of iron-pan or 'ragstone' which he collected 'on the northern edge of Snapewood'.

At Snape Wood ironstone was discovered during excavation of the railway cutting and was worked in mines consisting of galleries and cross-cuts on both sides of the railway from August 1857 to September 1858, the ore being sent to Staffordshire(19,20). The Ashdown Beds in the railway cutting consist of interbedded siltstone and fine-grained standstone. Some 12m of these beds are now exposed(21) in the central part of the cutting on its north face [6332 3017]. Particularly prominent is a hard, red-weathering silty siderite rock 0.46m thick. At the eastern end of the present exposure this bed dies out suddenly, but it is probably missing for a short distance only. Its south-easterly dip of 2° would bring it close to the cutting floor at the east end of the cutting, near an overgrown excavation [6340 3010] in the wood south of the railway, which is probably the mine entrance.(22) Le Neve Foster(23) wrote 'a great deal of raw ore still lies by the side of the railway'. Even today two large blocks of the ore, half-buried by ballast, are to be seen near the east end of the cutting. A thin section of one of them (E 47168) matches the 0.46-m bed exposed on the cutting face (E 47167). Both thin sections are of finely laminated silty siderite mudstone, with clay and quartz-silt laminae about 1mm thick that show much disturbance, prior to consolidation of the rock, by burrowing organisms. The rock consists of subangular quartz grains about 0.04mm in diameter with scattered mica flakes in a matrix of siderite rhombs of 0.001mm diameter. The detrital quartz is partly replaced by siderite. Heavy detrital minerals include green tourmaline zircon, apatite, and rutile. Hematite (X-ray powder photograph X 7358 by Mr. B.R. Young) coats joints in E 47167. Petrographically, the rock is very similar to the Upper Tunbridge Wells siderite mudstone from Broadfield Forest, differing mainly in its sedimentological features, i.e. its finer grain size and the presence of bioturbation. Gregory's analysis of the Snape Wood ore (Table 2 col.1), confirms the similarity with Lab. No 2488. The higher percentage of alumina and silica in the former probably reflects its higher clay content. In the mine, two beds were worked on the south south side of the railway. They were very irregular, dying out suddenly and reappearing at intervals(19). It is not known to what extent Ashdown Beds ironstones of this type were utilised for the iron industry of the Weald.

Gregory(18) dismissed his 'ragstone' sample (Table 2, col.6) as of little value, its iron content being too low for it to rank as an ore. Its high silica content may however result from its being derived from the Ashdown Beds, for Lab. No 2489 shows that material of similar origin in the Weald Clay can be rich in iron. Gregory's analysts(24) remarked on the high ratio of manganese to iron in the 'ragstone' sample.

The ironstone from minepits (690 188) south-east of Giffords Farm(18), 6km WNW of Battle was presumably a loose fragment from the ground surface. The pits as is usual are all filled in; no ironstone is to be found there at the present day.

The analysis of this rock (Table 2, col.2) and those of ironstone from near Crowhurst(25) (cols 3 and 4) and Sharpthorne(26) (col 5) are all similar and represent the best evidence to date for the composition of the Wadhurst Clay ore(27,28) on which the iron industry of the Weald was largely based. The high CaO content of each sample is noteworthy, as is the fairly high MnO content of the Giffords Farm and Sharpthorne samples. Ovenden(27) commented that the Giffords Farm analysis reveals almost the correct amount of lime and magnesia to provide a free-running slag at 1470°C; the temperature of a Wealden blast-furnace rendering unnecessary the addition of limestone to the furnace charge as a flux. Hallimond(30) remarked on the close resemblance of the Giffords Farm ore to typical Coal Measures siderite mudstones.

Acknowledgments

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Postscript. Since this paper went to press two further analyses of Wealden iron ores have come to the author's attention. They were made for Dr. R. F. Tylecote (in Crossley, D.W. 1975. Cannon - manufacture at Pippingford, Sussex: the excavation of two iron furnaces of c. 1717. **Post–Medieval Archaeology**, vol. 9, pp 35–37) and are shown in Table 3.

The Upper Hartfield iron ore analysis is closely comparable with analyses 2 to 5 in Table 2. The lime and magnesia contents are rather higher than those in the previously published analyses; the MnO content is near the average for analyses 2 to 5.

The analysis of roasted ore from Pippingford bears a marked resemblance to analysis 3 in Table 1. Its iron oxide content is lower than that of the Broadfields roasted ore, but its silica is correspondingly higher. It is not clear why the ore at a blast furnace site should have been roasted, as the indirect process is less dependent on high grade ores than is the bloomery process.

TABLE 3
Wealden iron ores from the Pippingford area

	1 %	2 %
SiO_2	8.9	17.9
Al_2O_3	3.25	5.8
Fe_2O_3		64.0
FeO	45.5	
MgO	1.84	1.3
CaO	6.2	0.8
Combined water	4.1	–
P_2O_5	0.37	0.7
MnO	1.28	2.8
CO_2	25.4	1.60
S	0.09	0.03
Total	96.93	94.93

1. Clay ironstone from Wadhurst Clay. Upper Hartfield, 1-inch Sheet 303 (c. 455345). Anal. Messrs Ridsdales, Newham Hall, Middlesbrough.
2. Roasted clay ironstone from Pippingford blast furnace site. 1-inch Sheet 303 (450316).

Anal. B.S.C. Special Steels Division, Swinden Laboratories.

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21 R. A. Bazley in C. R. Bristow and R. A. Bazley, The geology of the country around Royal Tunbridge Wells. Mem. Geol. Surv., 1972, p. 59; and on 6-inch geological map, sheet TQ 63 SW.

22 Straker (ref. 20, p. 291) gives a photograph showing the entrance open, and must have entered the workings, for he recorded wrought iron trolley rails still remaining.

23 In Topley (ref. 19), p. 337.

24 Messrs R. R. Tatlock and Thomson, ref 18, p.25.

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JHMS 10/2 1976

Work in progress

LYMM SLITTING MILL SJ 681875

Barry Johnson and Pauline Bearpark ©

Excavation of Lymm Slitting Mill took place in 1973[1] in conjunction with the landscaping of the area to form parkland, using the mill as a feature of historic industry.[2] However, due to the early completion date set by the contractors, the rolling room was not fully excavated and further work was carried out in this area by The North Cheshire Archaeology Group in 1975.

Some 34 sq m was excavated, the infill consisting of building rubble and sand to a maximum depth of 1.7m. This was probably from the restructuring of the mill due to the change from metal working to textiles in 1800.[3] Below this was the original working floor of small pebbles, coal dust and mill scale which was arranged on two levels, that on the north side, surrounding the furnace,being 1.4m higher than the main workroom. The raised floor was resting on clean sand and was retained by a substantial wall of tudor type brick. This wall continued round the lower metal working area, which had been extended at the north-west corner at a later date.

In the centre of the rolling room a cruciform brick foundation bed still survived to a height of nine bricks. Adjacent to the north side of this were two compacted piles of corroded metal flakes – evidence of a metal rolling operation, probably the slitting of iron. Power for this process was provided by the two water wheels, the axis of which passed on either side of the machine foundation (see plan).

Along the west side of the excavated area, and parallel to it, a second wheelpit was discovered, of similar size and structure to the first wheelpit[1] and apparently contemporary with it. Both had been raised from low to high breast shot, and held wheels of the same diameter (5.4m). The second wheelpit had been walled across both ends during later building reconstruction work; thus it did not appear on the 1800 plan,[3] and there was no evidence of it prior to excavation.

The more interesting finds include one half of a bronze bearing for a six-inch shaft, a piece of another bronze bearing for an eight-inch shaft, two furnace fire bars, several metal tools, and a large quantity of small pieces of iron.

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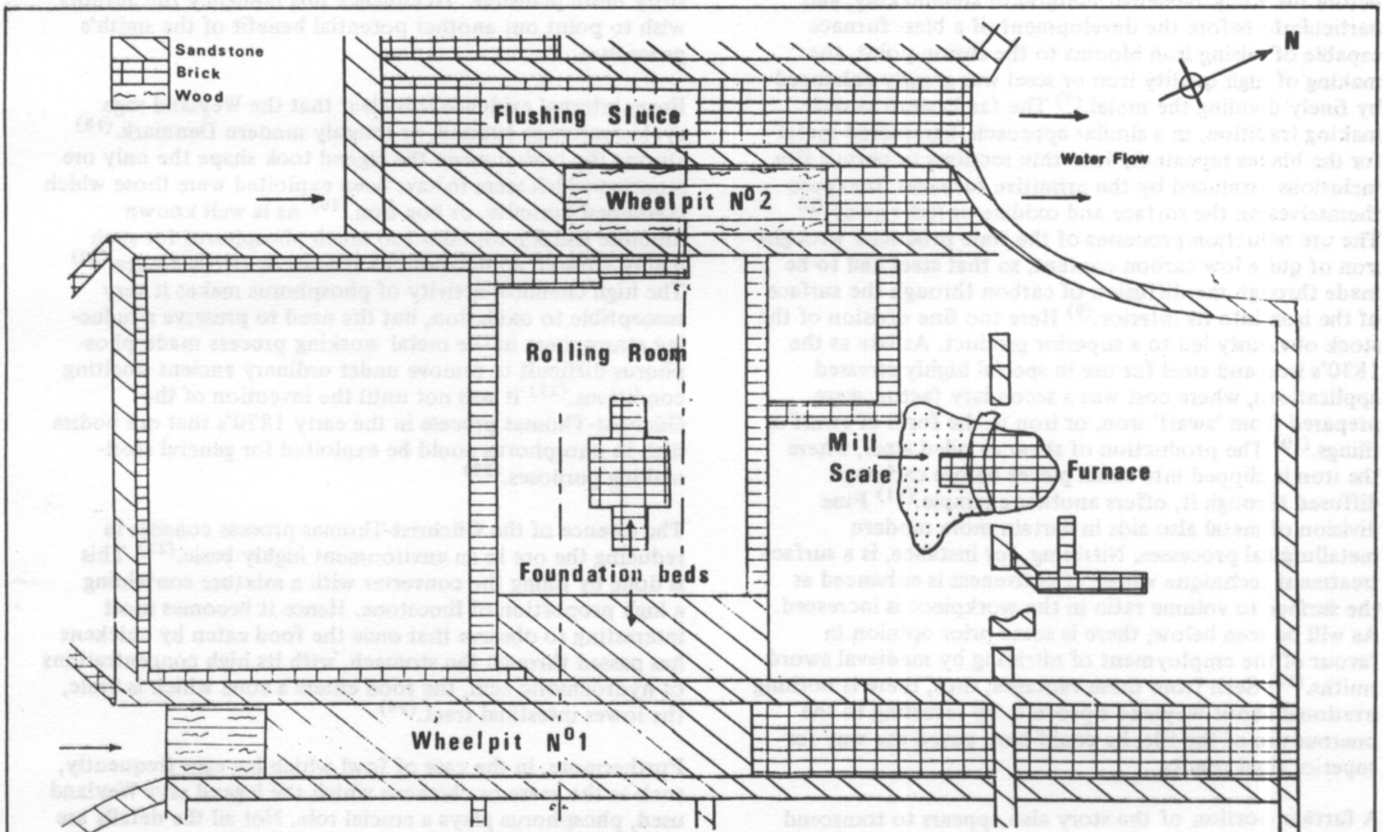
1 Cheshire Archaeological Bulletin No 2 1974, p 23–5, figure 8.

2 Current Archaeology No 45, p 312–4.

3 Deeds of the Danebank Estate, Lymm 1720–1824.



LYMM SLITTING MILL
1975 Excavation

The story of Weyland the Smith

An Ancient Gilchrist-Thomas Process?

Dennis Willen, Werner Soedel and Vernard Foley ©

Many of the most famous swords and pieces of armor mentioned in the medieval legends of northern Europe were attributed to Weyland the Smith.(1) In fabricating these items the smith is said to have used a technique which at first sounds farfetched.(2)

In the Theodoric von Bern saga, Weyland sets out to make a sword of unsurpassed quality.(3) He begins with an ordinary sword, produced presumably through conventional processes not discussed in the poem. The blade of this sword he files completely into filings. These are mixed with meal,(4) which is made into cakes, and the cakes are fed to 'tame birds',(5) probably geese or hens. Weyland then collects the droppings of the birds, puts the manure into his forge and thus recovers his metal. A sword made from iron processed in this fashion proves to be far superior to the original one, but Weyland is not satisfied. He repeats the process, and at the end produces a sword of matchless quality.

This tale seems to be the stuff of which legends are made, rather than the basis for a chapter in the sober history of metallurgy. It has generally been treated as such.(6) There are plenty of other obviously fictional elements in the story also. And yet there may be a deeper importance in it.

Consider first the filing portion of the story. In the age before the Kelly-Bessemer method of steelmaking, and particularly before the development of a blast furnace capable of raising iron blooms to the fusion point, the making of high quality iron or steel was greatly enhanced by finely dividing the metal.(7) The far Eastern sword-making tradition, in a similar approach, hammered metal for the blades repeatedly into thin sections to permit slag inclusions produced by the primitive furnaces to expose themselves on the surface and oxidize or flake away.(8) The ore reduction processes of the time produced wrought iron of quite low carbon content, so that steel had to be made through the diffusion of carbon through the surface of the iron into its interior.(9) Here too fine division of the stock obviously led to a superior product. As late as the 1830's iron and steel for use in special highly stressed applications, where cost was a secondary factor, were prepared from 'swaff' iron, or iron in the form of swarf or filings.(10) The production of shear or piled steel, where the iron is clipped into small pieces before carbon is diffused through it, offers another example.(11) Fine division of metal also aids in certain more modern metallurgical processes. Nitriding, for instance, is a surface treatment technique whose effectiveness is enhanced as the surface to volume ratio in the workpiece is increased. As will be seen below, there is some prior opinion in favour of the employment of nitriding by medieval swordsmiths.(12) Seen from these vantages, thus, there is nothing irrational about Weyland's process. By resorting to the onerous use of the file, he could have paved the way for superior final results.

A further portion of the story also appears to transcend myth status. In 1955 Thouvenin performed a portion of the Weyland experiment using a duck and examined the iron recovered from the droppings.(13) It was found to be completely free of slag. Since the best swords of the early middle ages were made by welding together small carburized iron strips,(14) and since slag is the enemy of good welds, the story takes on additional interest from this point of view also. Thouvenin did not comment on the biochemical processes involved, but it seems likely that the filings were pickled. The stomachs of birds contain juices which can reach quite high levels of acidity. For birds on ordinary diets, the pH level can reach 2.0. For fowl which have been starved, even higher levels are possible.(15) Significantly, the story says that Weyland starved his birds before feeding – three days the first time around, and a full week before the second feeding. Hence another surprising conjunction between myth and metallurgy appears.

Nor is it necessary to assume exotic circumstances to account for the origin of a procedure of this kind. As Balhausen has pointed out, birds will peck up and eat bright metal pieces of the size of filings.(16) Considering that in the Middle Ages iron, and especially steel, was at least a semi-precious metal, one might suppose that some smith hit upon the idea of burning chicken manure as a way of recovering metal otherwise lost. The proportion of metal lost to the file or the chisel, in the process of making a sword blade using ancient techniques has been estimated at as high as fifty per cent.(17)

These previous researches thus help to make the Weyland story more plausible. To enhance this tendency the authors wish to point out another potential benefit of the smith's procedure.

From internal evidence it is clear that the Weyland saga cycle centers in Jutland, or roughly modern Denmark.(18) During the period when the legend took shape the only ore scources which seem to have been exploited were those which contained limonite, or bog iron.(19) As is well known limonite usually contains too much phosphorus for such highly stressed applications as armour or sword blades.(20) The high chemical activity of phosphorus makes it very susceptible to oxidation, but the need to preserve a reducing atmosphere in the metal working process made phosphorus difficult to remove under ordinary ancient smelting conditions.(21) It was not until the invention of the Gilchrist-Thomas process in the early 1870's that ore bodies high in phosphorus could be exploited for general steel-making purposes.(22)

The essence of the Gilchrist-Thomas process consists in reducing the ore in an environment highly basic.(23) This is done by lining the converter with a mixture containing a high proportion of limestone. Hence it becomes most interesting to observe that once the food eaten by chickens has passed through the stomach, with its high concentrations of hydrochloric acid, the food enters a zone which is basic, the lower intestinal tract.(24)

Furthermore, in the case of fowl which lay eggs frequently, such as the geese or chickens which the legend says Weyland used, phosphorus plays a crucial role. Not all the details are fully clear, but it seems adequately plain that calcium is carried to the eggshell formation process in the bird from its storage site in the skeleton, on phosphate compounds.(25)

For several decades it has been observed that laying hens will remove phosphorus from the materials in their diet with great efficiency.(26) Any amount of this element not needed for the eggshell formation process is excreted through the kidneys.(27) In chickens the intestinal and urinary tracts have a common vent, but when the urine rejoins the feces the phosphorus is already neutralized. Thus it does not readily form new compounds with the iron.

Hence the possibility suggests itself that Weyland was able to reduce the cold-shortness of his metal by reducing its phosphorus content with his repeated biological processing. Beginning with material dangerously brittle at room temperature, he perhaps was able to anticipate the Gilchirst-Thomas process of one and a half millennia later. In this connection the repeated use of the birds, and the fine reduction of the metal take on a new significance. Even if the phosphorus were only removed from the surface of each filing, still the high ratios of surface to volume involved would seem to yield significant results, especially when the procedure was done repeatedly.(28)

Nor have the potential benefits of the process been exhausted. Analysis of existing sword blades of the period shows that their hardness can be due more to their nitrogen than to their carbon content.(29) Hence it becomes interesting to recall the comments on nitriding given above. The dung of birds is rich in ammonia, and the fine division of metal permits effective nitriding to occur quickly at temperatures well below red heat, or well within the capabilities of the primitive forge.(30) This aspect of the legend has received discussion by earlier commentators,(31) but no experiments seem to have been done to confirm the expected result, or to measure the amount of its effect. It is customary today to consider that nitriding can only occur if the steel contains traces of aluminum, chromium, or molybdenum. However, one instance at least exists in the literature wherein 1020 steel was successfully nitrided using urea.(32)

The authors are presently attempting to duplicate Weyland's results with a view to examining both the nitrogen and phosphorus aspects of the question. In view of the potentially unorthodox nature of the contributions made to the history of metallurgy by the outcome, however, it would be well to have the experiment duplicated. This is particularly true if samples of ancient iron are anywhere available for processing. With modern analytical methods the amounts involved can be quite small so that museum specimens need not be destroyed wholesale.

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1 Weyland should not necessarily be considered as an historical figure. His legend took form sometime before the seventh or eighth century. This follows from scenes from the Weyland story found on the Franks Casket, in the British Museum. See A.S.Napier, 'The Franks Casket', Furnival Miscellany, Oxford, 1901, 362–81. For a discussion of the possibility of a fifth century date, see Hilda R. Ellis-Davidson, **The Sword in Anglo-Saxon England; Its Literature and Archaeology**, Oxford, 1962, 108–8.

2 Compare the view of Theodore A. Wertime, **The Coming of the Age of Steel**, Chicago, 1962, 2–3.

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4 The German gives 'mehl', presumably ground wheat.

5. 'Zahme Vogel' in Theodoric von Bern. See Hecht and Hecht, op. cit. 206. For species identification, see Ellis-Davidson, 159n.

6 See for instance R.J. Forbes, **Man the Maker**, New York, 1950, 33–4. The story was taken seriously by Biringuccio, however, who knew a version of it. See **Pirotechnia**, Cambridge, Mass., 1959, 70. He went so far as to try various dungs.

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9 Leslie Aitchison, **A History of Metals**, New York, 1960, 1960, I, 112–13; 140–42.

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12 See notes 29–32 below.

13 Edouard Salin, **La Civilisation Merovingienne, Part 3, Les Techniques**, Paris, 1957, 96n.

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15 The use of swaff iron in Birmingham in the 1830s (see note 10 above) featured pickling in sulphuric acid. For avian gastric juices see D.S. Farner, 'Gastric Hydrogen Ion concentration and Acidity in the Domestic Fowl', **Poultry Science**, 22 (1943), 79.

16 C. Balhausen, 'Notions concerning the Weyland Saga', **Powder Metallurgy Bulletin**, vii (1956), 69–72.

17 Ellis-Davidson pp.27, 160. Grinding probably was used only for the final finishing, as it was slower than filing. Moreover, the first datable appearance of the rotating grindstone in Europe comes in the Utrecht Psalter of 850 AD. See Robert S. Woodbury, **History of the Grinding Machine**, Cambridge, Mass., 1959, 13–14. Woodbury's figure 13 shows this, and also apparently filing.

18 Nidung, the king for whom Weyland makes his sword, is a ruler in Jutland. See Hecht and Hecht, 199. In addition, local sites in Denmark are associated with Weyland or with famous swords to this day. See Ellis-Davidson, 108, 146.

19 Coghlan, 15, 49–52.

20 For an analysis of iron produced by forges reconstructed according to archaeologically determined specifications, as well as an analysis of prehistoric Danish bar iron hoards, see Olfert Voss, 'Jernudvinding I Danmark I Forhistorisk rid', KUML, 1962, 7–32; and Robert Thomson, 'Forsog pa Rekonstruktion af en Fortidig Jernudvindings proces', KUML, 1963, 60-74. From these studies one may assume the locally available iron contained roughly 0.7 to 0.8% phosphorus. cf. Coghlan, 44.

21 Coghlan, 39. Thomson's experiments verify the archaeologically supported evidence that phosphorus levels about twenty-five times that of modern steels and irons were produced by the ancient smelters.

22 Aitchison, II, 515–18.

23 The converter was lined with dolomite.

24 Harry W. Titus, The Scientific Feeding of Chickens, Danville, I11, 1961 (4th ed.) 39–40; and interview with T. R. Cline of the Poultry Science Department, Purdue University.

25 H. Salem and H. Reds, 'Calcium and phosphorus Metabolism and Shell Formation', Poultry Science, 34 (1955), 197–205; T. G. Taylor and F. Hertelendy, 'Changes in the Blood Calcium Associated with Egg Shell Calcification in the Domestic Fowl', Poultry Science, 40 (1961) 108–114; 115–123.

26 W. Ray Ewing, Poultry Nutrition, Pasadena, Calif., 1963 (5th ed.), 575–7.

27 Ibid., 577.

28 If the metal were to be ingested in sulfide form it might be absorbed into the birds' metabolism; interview with T. R. Cline. In this connection it is interesting to note that Weyland experienced metal loss from his first feeding. Similarly, Thouvenin found that ducks absorbed some of the iron fed to them.

29 Smith, 4n.

30 Typically nitriding is done at temperatures ranging from 500 to 550C°: This is a low red heat. Weyland would have been able to achieve white hot temperatures or he would not have been able to weld iron as the legends describe. Nitriding requires heat soaking of up to several days duration. Thus it is interesting that in the Siegfried legend a similar length of time is specified for the forging process. Also, when only filings are involved, the time required for hardening a significant portion of the metal is much reduced.

31 H. Coghlan, 'Etruscan and Spanish Swords of Iron', Sibrium, iii, 1956–7, 168; Smith, 4.

32 R.P. Dunn, W.B. Mackay, and R.L. Dowdell, 'Urea Process for Nitriding Steels', Transactions, American Society for Metals, XXX (Sept., 1942), 776–91.

Notes

RENEWED INVESTIGATIONS OF IRON MINING AND SMELTING IN THE HARZ AND AT SOLLING, GERMANY: after reconnaissances of Wedding (1881) and Bode (1928) further slag deposits had been found since 1969 in the Harz and in the Harzvorland (ie. in regions situated in the west of Harz). Systematical mapping operations and registrations (1:5000, 1:2000) started in the iron ore bearing area of Lehrbach, near Osterode. In general, three main types types of medieval iron smelting sites are to be distinguished: 1) small bloomeries outside settled territory, close to opencast mining places along brooks and slopes of minor valleys. For instance, smaller bloomery sites were attested in the vicinity of Solling, dating from the 15th and 16th centuries AD. They are based on local Middle Buntsandstein and Lias iron ores: 2) bloomery slag finds dispersed in abandoned medieval villages of the Harzvorland: 3) large smelting sites on Harz rivers where Stücköfen or blast furnaces are connected with drainage and pond systems serving water wheels.

Except for the excavations made by the late W. Nowothnig (1965), who discovered several smelting sites of the 10th–14th centuries, no archaeological excavations of bloomeries have been undertaken. They are envisaged, however, for the near future. The Geographical Institute of the University of Göttingen intends to centralize the work and to conserve all available material from previous campaigns. Some analyses of slags from excavations by Bode and Nowothnig were carried out in various steel works or at the Institute of Metallurgy of the Technical University at Clausthal.

D. Denecke, Göttingen
after C.P.S.A.

ROMAN IRON FROM AUGSBURG TESTED. Professors Ruckdeschel and Fischer, with the Technical University of Augsburg, submitted three Roman iron objects from the Augsburg-Oberhausen assemblage to metallographical examination and performance tests. The finds date from the beginning of the AD area. Two rods (round and flat bar) were tension-tested (32.2 – 35.7 kp/mm^2). They seemed to be more resistant than modern steels but they were heavily slagged. A waller's hammer was made of steel with 0.22 per cent carbon and its peen was probably carburized up to 0.8 per cent.

After D. Reitmeyer in V.D.I.
Nachrichten 33, Aug. 15th, 1975, p.6.

THE POSSIBLE APPLICATION OF FISSION–TRACK COUNTING TO THE DATING OF BLOOMERY SLAG AND IRON. A number of bloomery sites and assemblages of iron objects cannot be dated by archaeological methods. Radiocarbon dating of wrought iron and steel could be of only limited importance, eg. in European conditions, since it involves a large sample. The writer, therefore, discusses some possibilities of applying fission-track dating to the study of bloomery slags. Several preliminary tests were made (as part of a series of exploratory experiments concerned with the possible sources of archaeological evidence presented by ancient slags. This brief series of observations is presented in the hope that the technique might be examined in depth by other workers.

In accordance with the published descriptions of other workers, the surface of a fragment of bloomery slag was ground flat and brought to a highly polished finish. The surface was then etched for 20 seconds in a 10% solution of HF, washed, dried with a 50:50 mixture of methanol and ethanol, and then examined through an inverted metallurgical microscope. Initial examination at a magnification of x750 revealed (on scanning the whole surface area – approximately $15cm^2$) a number of potential tracks which were most easily seen in the fayalitic dendrites in the slag. Five other slag sections were also polished and etched with HF (at varying concentrations from 1%–10%, and at times varying from 10 seconds to 1 minute); additional surfaces were prepared by regrinding and polishing these sections. In an effort to obtain better resolution, attempts were made to scan the prepared surfaces at a magnification of x1500 using an oil-immersion objective. This proved unsatisfactory for a number of reasons, and was rejected in favour of scanning at x 750. In all cases, features which corresponded with the descriptions of fission-tracks observed by other workers were seen. However, since no facilities for irradiation of control samples were available to the writer it must be stressed that (after the elimination of definitely spurious features) identification is not certain. In addition to the examination of slag lumps, a number of metallographic sections of bloomery iron which were notable for the amount of entrapped slag they displayed were also prepared and examined. Again, what appeared to be tracks were found in the slag inclusions. At this point it was not possible for the writer to continue investigations. However, the following points are worth noting.

1. Another series of tests showed that it is possible to recover charcoal (mainly in a finely comminuted form) which has been sealed in bloomery slag during the smelting process. If a sufficiently large single block of slag is taken, then it is possible to recover an uncontaminated sample of charcoal which is large enough for meaningful C–14 age estimations to be made.

2. Assuming that the features observed by the writer were indeed fission-tracks, then C–14 age-estimations made on entrapped charcoal from the slag being studied should provide an immediate and directly related scale for calibration of track counts to absolute age in C–14 years.

3. C–14 dating of massive slag blocks seems, in itself, to offer the ideal charcoal sample which is the result of a single, brief episode, and which is uncontaminated by being hermetically sealed in by the slag. (Obviously this will only be of archaeological value if the slag can be demonstrated to be in a meaningful primary context – ie. not scattered debris). By comparison, fission-track age-estimation is much more time-consuming, with a great deal of effort going into preparation and track-counting alone. It would therefore not seem a viable technique for dating slag blocks.

4. However, where it could prove invaluable is in the age-estimation of those iron artifacts which contain enough entrapped slag from which counts can be taken. The age-estimations could be made from scales calibrated by C–14 dating of a significant number of massive slag samples. So many iron artifact types are not closely datable because of their simple shapes, and even study of comparative technology will only provide a rough guide. Thus, any technique which offers the potential for constructing even reliable relative sequences for iron artifacts, within or among assemblages, is worth close scrutiny.

5. A number of difficult problems of technique must be overcome before such theory can become practice. These These are particularly severe in terms of the low numbers of pits which can be expected to occur in small inclusions (due to the very small amounts of radioactive elements present), and in the precise estimation of the volume of material from which counts are taken. In the former case, the observation of the much more numerous disruptions caused by alpha-particle recoil could possibly produce results of greater statistical reliability, although because of their much smaller size, preparation for electron microscopy would be entailed.

Some thought has been given to the second set of problems and, while the issues of precise techniques that might work are too broad to be presented in this summary, the writer would be more than glad to correspond with anyone wishing to pursue the question further.

References

Scott, B. G. (1974) 'The application of techniques of physical examination to archaeological research', in Perspectives in Irish Archaeology, Belfast, 1974, pp 108–9, and 118–120.

B. C. Scott, Belfast.

EXCAVATIONS OF PRE-HISTORIC BLOOMERIES AT COLCHIS (WESTERN GEORGIA). From 1970 till 1974, after an intermission of ten years, renewed systematic field work was directed to the uncovering of ancient iron smelting places in Georgian Transcaucasia. Original field work was started by the late I. A. Gzelišvilli. The recent excavations concerned three main areas in the south of ancient Colchis: Djikhendjuri (4 sites), Legva (1 site), and Čarnali (1 site) in the Čoloki-Očkhamuri and Čorokhi river basins, and a newly touched area in the central part of Colchis (Supca river basin).

The bloomeries used to be equipped with one relatively large open smelting hearth (ca. 80 cms in diameter, depth about 105 cms), lined with stones and refractory clays. The air system is attested by long clay tuyeres; several of them have a curved shape. Besides small fragments of slag found in furnace pits, large slag blocks were found outside the furnaces. Stone blocks with dish-shaped hollows represent traces of ore dressing. Among ores there were magnetite sand and pure hematite. Reheating and forging plants for treating blooms were also found (Čoga, Ceckhlauri).

Some corrections of the previous Gzelišvilli's dating (13th–12th centuries BC) seem to be necessary, though the problem is not yet definitely solved. The dating is based on grey polished pottery (Ceckhlauri II– 9th century BC). Trials were made in order to fix the relative (and absolute) chronology of individual sites by means of archaeomagnetic tests. The following preliminary chronology is suggested: bloomeries Čarnali I (1 and 2), Legva I–1, and Askana I = 10th–9th centuries; Ceckhlauri I, II, Djikhandjuri I–1, and Čoga II = 9th century; Djikhandjuri I–3, and IV, possibly Čoga I = 8th century; Djikhandjuri I–3, II, and III, and Čoga III = 7th century BC. The bloomeries discovered evidently belong to the oldest iron smelting sites known. Moreover, the region of the later Colchis seems to have been very important in supplying SW Asia with iron in the earliest Iron Age. Production presumably went beyond the limits of local demand. Further workshops are still buried.

After D. A. Kkhakhutaysvili, Tbilisi.

METALLOGRAPHICAL INVESTIGATIONS OF MEDIEVAL IRON OBJECTS EXCAVATED IN THE ST DIONYSIUS CHURCH AT ESSLINGEN, FEDERAL GERMANY. The Max-Planck Institute at Düsseldorf has further examined about forty specimens won during excavations from beneath the St Dionysius church area at Esslingen. Some of the Slags could be defined – according to their mineralogical and chemical compositions – as bloomery waste. Among the various artifacts of iron, nails and hooks usually consist of wrought iron enriched in phosphorus. Some of them were piled wrought iron and carbon steel.

Knives, wedges, scissors, and chisels were composed of iron and hard steel with welded-on edges and heat treated. A typical well-made and hardened implement is a chisel from the 13th century AD. Objects of a later date (16th–18th century) occur sporadically among ironmongery dating from the 9th up to the 15th century. They allow some useful technological comparisons. Their construction scheme is similar to older artifacts, but the scarcity and type of slag inclusions show that the materials used belong to the more refined varieties of the 'New Age'.

EXAMINATION OF MEDIEVAL IRON OBJECTS FROM SINDELFINGEN, FEDERAL GERMANY. During excavations carried out by Dr Barbara Scholkmann (Landesdenkmalamt Baden-Wurttemberg) there were picked up numerous iron artifacts, originating in medieval layers of the 11th–15th century AD. Metallographical investigations of a set of them were undertaken at the laboratory of the Max–Planck–Institut at Düsseldorf. Most irons such as horseshoes, bolt-points, tongs, a hoe, were manufactured usually by piling wrought iron or soft steel plates, in general very rich in phosphorus. Presumably local dogger iron ores were used. A sickle dating from the 14th century deserves special attention. It was equipped with a welded-on hard steel edge. Further, a masterly made piece was a short pattern-welded knife with a narrow damascened strip and hard steel, marquenched edge. Its dating spans the period from the second half of the 13th to the second half of the 14th century.

An alcoholic solution of picric acid was employed for etching. It reveals not only differences in the carbon content but also phosphorus variations.

D. Horstmann, Düsseldorf.

Book reviews

Keith Kissack. Monmouth: the making of a county town. Phillamore, 1975, £5.75.

The very full account of Monmouth's development makes an interesting and entertaining contribution to one aspect of metallurgical history – the use of cinders produced in past ages in 18th century furnaces – in Chapter IX, pp 290–293. The refuse from medieval bloomeries had been discarded in dumps, either as islands in the river or as cinderhills. Yarranton and Pepys noted the value of these deposits, but the town did not appreciate it until the end of the 17th century. In 1703 the council went into the business of raising and selling cinders, and even offered to buy cinders for resale. Within a few years 'the council was thinking of little else', and understandably so, as the trade was providing the bulk of its income. It became customary to include special clauses dealing with cinders in conveyances, and the lord of the manor, and private prospectors, provided the council with competition. The 13th century town walls were destroyed in the search for cinders and a new road had to be built in Overmonnow. The diggers enthusiasm was such that part of an inn collapsed, and the quay wall subsided. An alehouse was offered for sale 'with its iron cinder mine' in 1769, and the trade continued to be profitable through most of the century.

H W Paar

Amina Chatwin: Cheltenham's Ornamental Ironwork – A History and Guide. Published by the Author at 6 Montpelier Street, Cheltenham, 1975. £1.50.

Cheltenham is very fortunate to have found in the author someone who takes an interest in industrial archaeology and carries the interest to a logical conclusion: this is an excellent paperback full of photographs, drawings, copies of old prints and a delightful text on the ironwork of a particular place. She gives a brief account of early manufacture of cast and wrought ironwork to acquaint the reader with a basic knowledge of the book's discussion. From this follows the history of the development of Cheltenham and its ironwork divided into three periods and followed by detailed chapters on railways, gates, oil lamps, gas light, electric light and pillar boxes. There are notes, references and an index following an outline of three known firms in the trade.

It is a long time since I have seen such a first class presentation ofa topic within the field of industrial archaeology in a form which is both acceptable to the general reader and the enthusiast as well. Amina Chatwin should be congratulated on an absolute gem of balanced recording which will doubtless spur further interest both in Cheltenham and elsewhere. It is the best £1.50 on the history of ironwork on the market and I only wish I lived in Cheltenham myself to explore this intriging aspect of our industrial past.

J W H Silvester

Kenneth Hudson: Industrial Archaeology – A New Introduction. John Baker, London, 1976. £6.25

Once more this well-known introduction to industrial archaeology has been revised and reset. Now in its third eiditon it shows the strength of commercial interest in good books on this recently established subject. Kenneth Hudson, no stranger to the circle of devotees within the field of industrial archaeology, is fast becoming a high priest on the art: his explanations cover the wide ranging area of this branch of archaeology with a texture designed to encourage the reader in his new found interest. More accurately as with any exponent and enthusiast, he relates his boundaries to the subject field and gives a tasteful account of those features he obviously considers important. This is no handicap to the reader and indeed it is a pleasure to find the odd point with which another enthusiast can quibble: any enthusiasm breeds its own pedantics!

I owe the author a considerable debt in spreading interest in this marvellous facet of history which for me ended yesterday and I gratefully acknowledge his help. This edition is an excellent example of his many written forms of encouragement. The book is divided into eleven chapters devoted to explanations of the subject, its value and approaches by different students whose publications make them widely known and the topic matter of the subject. There are lists of local societies and films, a gazetteer and and index, some excellent illustrations, maps and plans all of which are well labelled and the whole effect is one of pleasure to have such a book in one's possession. The book's selling price places it within the range of the more than 'mildly interested' student of industrial archaeology, and it is value for money.

J W H Silvester

Abstracts

GENERAL

A R Williams. Problems with the composition of armour. *Institut Suisse d'Armes Anciennes, 1972/74 Rapport 1/2 26–28.*

According to several specimens which could be examined metallographically, the armour of the 15th century AD was harder since its plates were case-carburized and quenched. The armour of the 16th–17th century was softer, made of homogeneous steel, but tough.

K C Barraclough. Crucible steel manufacture. *Metallurgist and Materials Technologist, 1974,* **6** *(2), 71–79.*

The development of crucible steel manufacture is traced from its invention in the mid-eighteenth century. A detailed description of the crucible process used at the end of the nineteenth century is presented.

MG

A A Gordus and J P Gordus. Neutron activation analysis of gold impurity levels in silver coins and art objects. In Book. *Archaeological Chemistry (Advances in Chemistry), American Chemical Society, Washington DC 1974,* **138,** *pp 124–147.*

The levels of gold impurity in most silver coins minted more than 100–200 years ago appear to be an indication of the levels occurring in the original silver sources. Thus, it is often possible to group coins according to their gold: silver ratios and to suggest possible geographic origins of the silver. During the past six years over 8000 coins and metallic art objects were analyzed using samples in the form of metal streaks on etched quartz tubing. Summarized here are analytical data for Sasanian (Persia: 224–650 AD) coins and silver art objects as well as Umayyad (Persia: 661–750 AD) and Byzantine coins. Data are also presented on the identification of modern forgeries of ancient and medieval coins and Sasanian art objects, the use of Mexican and South American (Potosi) silver in Spanish and other European coinage and its relationship to the price revolution of sixteenth-century Europe, and the questionable honesty in the minting of Zapatista Revolutionary Mexican coinage of 1914–1915.

AA

H Gerbeauz. The history of welding and special processes. *Sciences et Techniques, 1974 (13), 30–35. (In French).*

The history of welding is traced from its origins to present times. Forge welding, fusion welding, resistance welding and arc welding were introduced in the period 1860–1901. Successively, from 1925 onwards a series of important new processes have been developed. Some of these processes, including ultrasonic welding and explosive welding, are briefly described.

MG

D R Cooper. Coins and coining. *Copper, (January and May 1969), (1 and 3), 2–5 and 14–17.*

This is a brief review of the use of copper in coinage through the ages. It discusses earliest forms of currency and then goes on to the role of copper and alloys in coinage. The second part deals with minting practice from medieval times to the present day.

WAO

J A Charles. Arsenic and old bronze. Excursion into the metallurgy of prehistory. Sir Robert Horne memorial lecture. *Chem. Ind., (London), 1974 (12), 470–474, 7 refs.*

A review, especially of the place of As–Cu alloys in Bronze Age technology.

BRITISH ISLES

B G Scott. Some notes on the transition from bronze to iron in Ireland. *Irish Archaeological Research Forum, (Belfast), April, 1974, 9–24.*

Certain objects lead the author to the suggestion that some rudimentary iron working took place in Ireland already during the 7th–6th centuries BC.

B. G Scott. The application of techniques of physical examinations to archaeological research. *Perspectives in Irish Archaeology (Association of Young Irish Archaeologists), ed. by B G Scott (Belfast) 1974, 107–119.*

Survey of some methods used in the research of Irish iron objects. Proposals for fission-track dating of bloomery slags, a few metallographical analyses (early medieval axe, pattern-welded sword).

G C Boon and H N Savory. A silver trumpet brooch with relief decoration, parcel-gilt, from Carmarthen, and a note on the development of the type. *Antiq. Journal, 1975,* 55 *(1), 41–61.*

In discussing the typological significance of this fine brooch, dated to AD 25–50, the authors consider (42–44) the method of manufacture. The analysis (80.1% Ag, 15.8% Cu, 2.6% Zn, 1.2% Pb, 0.1% Fe) suggests that zinc-enriched copper may have been used for the alloying metal. The brooch was cast using a lead model as pattern. Manual cleaning-up of the casting was slight. Parcel gilding (using gold dust in an amalgam with mercury) is confirmed by spectroscopic detection of Hg.

D R Wilson (Ed). Roman Britain 1972. I. Sites Explored. *Britannia, 1973,* 4, *271–337.*

Dolaucothi, Carms.: timber structure connected with processing of auriferous quartz.

Chesterholm, Northumberland: bowl furnaces for bronze and iron production in 4th century timber buildings in vicus of fort.

Ebchester, Co Durham: hearths, crucibles, and bronze dross in fort.

Manchester: 1st and 2nd century metal-working area outside Roman fort.

Quernmore, Lancs.: iron-roasting hearth in 1st/2nd century industrial site.

Chester: Stone-lined furnace and much metal-working slag in legionary fortress.

Northwich, Ches.: six iron-reducing furnaces in vicus of fort.

Middlewich, Ches.: five iron-working furnaces of 2nd/3rd centuries (probably smithing).

Godmanchester, Hunts.: 2nd century metal-worker's shop: bowl-shaped smithing furnace, four shaft furnaces, and crucibles.

Wakerley, Northants: iron-smelting furnaces.

Broadfields, Sussex: 1st–4th century settlement has produced 32 iron-smelting furnaces.

Brenley Corner, Kent: hearths and iron slag in Roman roadside settlement.

Northchurch, Herts: ironworking site with two bowl furnaces, pre-3rd century AD.

Cirencester, Glos.: large amount of iron slag in association with timber building of early military period.

D R Wilson (Ed). Roman Britain in 1973. I. Sites Explored. *Britannia, 1974* 5, *397–460.*

Aberffraw, Anglesey: evidence of small-scale ironworking in Roman fort.

Cae Metta, Caerns.: slag and crucible in enclosed hut-group.

Monmouth: furnaces associated with iron-working.

Middlewich, Ches.: 2nd and 3rd century smithing and scaling furnaces of circular and rectangular types, forging blocks, and slag.

Winterton, Lincs: ironworking in villa during late 4th century.

Wroxeter, Salop: industrial area between town and Severn originally devoted to iron working (armour, weapons), but later replaced by major glass industry.

Wakerley, Northants: evidence of large-scale iron-smelting in late Iron Age and Roman period.

Wendy, Cambs: much iron slag, with iron hipposandal and ox-goad, found at 1st–4th century settlement where Ermine Street crosses River Rhee.

Hacheston, suffolk: 3rd century iron-smithing furnace in settlement.

Cirencester, Glos: iron slag and furnaces within Roman town.

Gatcombe, Som.: two-roomed masonry building used as smithy: each room contained smithing furnace and yielded waste and coal from iron working (late 3rd to late 4th centuries).

Tarrant Hinton, Dorset: hearth filled with charcoal and cerrusite in villa complex suggests lead working practised.

Broadfields, Sussex: site covers 12 ha, includes ore-roasting facilities, 36 shaft furnaces, three slag dumps, water reservoir, puddling pit, and blacksmith's workshop containing stone-built forge.

Garden Hill, Hartfield, Sussex: iron-working in association with 2nd century buildings.

T B Page. Excavations at Edward Street, Lewes. *Sussex Archaeol. Collect., 1973,* 111, *113–4;*

A rescue excavation in Lewes revealed a pit containing late 13th and early 14th century pottery, into which a small smithing furnace with an integral tuyere had been inserted. The furnace was renewed at least twice. Large pieces of impure copper and melting slag suggest that the furnace was used for the melting of copper; no traces of bronze or brass were revealed by analysis.

A Jackson. The Rise and Fall of the Open-Hearth (for Steelmaking). *Ironmaking and Steelmaking, 1976,* 3 *(1), 1–9.*

This is a historical account of the development of the gas-fired open-hearth furnace in the UK from its beginnings in the mid 1850s to its decline in the late 1960s. Brief descriptions are given of technical developments contributing to improved furnace efficiency, especially from the early 1920s, when the author first embarked on his notable career in the steelmaking industry.

Anon. Old Coke Ovens Unearthed in Scotland. *Foundry Trade Journal, 1975,* **139**, *(3072), 669.*

Four beehive ovens of the type used for producing strong coke for iron-smelting and other metallurgical process have been unearthed during rehabilitation work at Plean No 3 Colliery, Stirlingshire, Scotland. Three of the ovens have been carefully filled-in but one remains visible. The planning development committee of the Central Regional Council at Stirling has recommended that this partly excavated oven be consolidated as it stands at a cost of £1,000. The Plean district was noted for its coking coals.

C McCombe. Papplewick – A Triumph of the Founders' Skill. *Foundry Trade Journal, 1975,* **139**, *(3075), 881–882.*

Brief details and some illustrations of the remarkable decorative brass and iron castings in the engine house of this water pumping station near Nottingham. It is intended to steam the two beam engines, installed between 1883 and 1885, on several weekends during the year – details from Secretary, Papplewick Pumping Station Inst., Mr. G. C. Bond, Pearl Assurance House, Friar Lane, Nottingham, NG1 6BX.

Anon. Grimthorpe on Bells. *Foundry Trade Journal, 1976,* **140** *(3079), 225–232.*

More extracts from Lord Grimthorpe's 'Rudimentary Treatise on Clocks, Watches and Bells for Public Purposes', 8th edition, 1903, recently republished in facsimile by E. P. Publishing Limited, Wakefield. This extract deals with early history, and mentions some of the more prominent bellfounders. There follows technical details on the shape of bells and the composition of the bell metal, and a discussion of methods for making the mould. These extracts are illustrated with photographs of moulds in various stages of preparation.

W Johnson, A G Mamalis and H Hunt. Small spherical lead shot-forming from the liquid, using a shot tower. *Metallurgia and Metal Forming, 1976,* 43 *(3), 68–72.*

The authors review references in the literature to the techniques for making lead shot, the earliest and most extensive appearing in Micrographia, by R Hooke, published in 1665. Traditionally, the lead was alloyed with orpiment (arsenic trisulphide), known from very early times for its ability to give lead the appearance of gold. Polishing by rotating in a barrel with graphite or other substances, and the burnishing of tin-plated shot so that the hands or guns are not soiled and that the flesh of game when shot is not contaiminated with lead are also mentioned. The shot-tower seems to have been an English invention. In 1963 there were four shot towers remaining in England: one at Newcastle, erected 1797, 30ft diameter and 175ft high but not at work in 1963: one at Edmonton, built 1808, one at Chester, and one at Bristol, apparently constructed in 1783, and still (1976) being worked by the Sheldon Bush and Patent Shot Co. The London Shot Tower, incorporated into the South Bank Festival Hall Site for the 1951 Exhibition at King George VI's request, had been demolished by 1963.

Laboratory experiments in the manufacture of lead shot are described. Despite additions of orpiment to the lead, and increasing the distance of fall to 31m., satisfactory shot was not obtained, and the experiments are regarded as drawing attention to an interesting though difficult practical and theoretical problem.

D R Wilson (Ed). Roman Britain in 1974. I. Sites Explored. *Britannia, 1975, 6, 221–283.*

Piercebridge, Co. Durham: workshops containing kilns and bronze-working debris (including crucible with copper still adherent) in vicus of fort.

York: coin moulds for casting late 2nd and 3rd century forgeries in industrial area.

Castleford, Yorks: smithing hearth and possible small bowl furnace in buildings alongside Roman road.

Wilderspool, Ches.: smithing hearth in area distinct from known industrial settlement.

Derby: fifteen hearths or furnaces of various types, some associated with iron working, in industrial settlement.

Thornhaugh, Cambs: shaft furnace for iron smelting, still standing 0.6m high, seven bowl furnaces, and rectangular masonry chamber, in Sacrewell villa (after abandonment).

Ashton, Northants: five furnaces and stone-lined tank in 2nd century industrial settlement. Finds include anvil, smith's hammer, iron nails and slag.

D. W Crossley. Ralph Hogge's ironworks accounts, 1576-81 *Sussex Archaeol. Collect. 1974,* **112**, *48–79.*

An edited transcription, with introductory essay, of the accounts kept by John Henslowe, manager of Hogge's ironworks on the southern fringes of Ashdown Forest. The accounts (published with the aid of a grant from the Historical Metallurgy Society) provide valuable information about the operation and manning of the blast furnaces and the iron market in the late 16th century.

J P Wild. Roman settlement in the Lower Nene Valley. *Archaeological Journal. 1974,* 131, *140–170.*

In a general survey of Roman settlement in this important economic region, the author discusses evidence of the exploitation of the iron ores of the Forest of Rockingham. Sites are recorded at Bedford Purlieus, Thornhaugh, Orton Longueville, Ashton and Bulwick. Comparative plans of furnaces are presented: they seem to be of the normal shaft bloomery type.

A and V Rae. The Roman fort at Cramond, Edinburgh: Ecavations 1954–1966. *Britannia, 1974, 5, 163–224.*

(181–183) The Roman fort revealed in one of its earlier phases a building containing a hearth surrounded by bronze scrap and a 'kiln' with waste lead nearby. There were also two tanks in the vicinity, believed to be associated with metal working.

S R Harker. Interim Report . . . on the Excavations at Springhead. *Archaeol. Cantiana, 1972,* 87, *229–230.*

Evidence of further metal-working activity in this temple precinct was revealed by large hearths, iron slag, charcoal, and burnt clay.

W J Botting. Romano-British ironworking site at Ludley Farm, Beckley. *Sussex Archaeol. Collect., 1973,* **111**, *111.*

A large deposit of iron slag and cinder in Brunthouse Wood produced coins and pottery dated to the 2nd century AD.

EUROPE

J Mossler (Mrs). Tools and Handicrafts. Observations on iron finds at Magdalensberg, Kärnten. *Annalen des Naturhistorischen Museums in Wien, 1974, 78, 75–94.*

A short survey of iron implements found in the oppidum of Magdalensberg, Carinthia. The collection includes blacksmith's and jeweller's tools (a hammer, crucible tongs, files, chisels). The published objects belong according to their shape to the early Roman, or Roman period.

B. Lambot. Stamped La Tène sword found in the Ardennes. *Bulletin de la Société Préhistorique Francaise, 1974,* **71**, *218–224.*

A stamped Celtic sword from Acy-Romance dating from the first half of the 1st century BC. Some remarks on its technology (piling, etching, cold forging) but without any metallographic analysis. To the sword belongs a sheet iron ornamented scabbard.

R Spehr. The daily lives and social economic structure in the Steinsburg-Oppidum. *In: Moderne Probleme der Archäeologie (K H Otto – H J Brachmann, ed.). Berlin, 1975, 141–175.*

A modified version of previous papers. The iron working production of the oppidum at Steinburg (Central Germany) was delivered on a broad scale into its peasant environment. Some data on metallographical analyses, conclusions drawn from the dimensions of artifacts, blacksmith's tools.

M Sönnecken. Result of a rescue excavation in Öneking/ Lüdenscheid. *Se Märker, 1974/5,* **23** *169–170. (In German).*

A rescue dig of a bloomery site (8th–9th centuries AD). Heavy slags, destruction of a furnace, a tuyere of iron.

R Halleux. The problem of metals in early science. *Bibliothèque de la Faculté de Philosophie Lettres de l'Université de Liège CCIX. Paris, 1974, 237pp. (In French)*

A treatise on the nature of the notion 'metals' in early antiquity has an appendix No.3 which discusses the problem of the existence of cast iron manufacture in the Classical period. In the author's opinion cast iron must have been an exceptional, if not accidental result of siderurgical operations. Aristotle in his description did not consider the fact that any generalization did not correspond to the contemporary reality.

V D Gopak. Blacksmith's craft of ancient Slavs in the Middle Dnieper river basin. *Archeolohiya (Kyyiv), 1975,* **18**, *15–22. (In Ukrainian).*

A short summary report on 85 metallographically analysed knives, chisels, axes, awls, scissors, tongs, hammers, slips, ploughshares, sickles and arrowheads from sites of the 6th–7th century AD. Wrought iron or mild steel construction with carburizing.

H G Steffens. Iron smelting furnace in Forst Stühe, Gem. Döttlingen, Ldkr. Oldenburg. *Nachrichten aus Niedersachsens Urgeschichte, 1974,* **43**, *191. (In German).*

Rescue excavations of 32 iron making features: includes 16 refining hearths, 12 slag blocks from hearths of furnaces, charcoal burning pit. Dating uncertain, presumably about the change of the BC/AD eras.

Yu Selirand. Estonian groups of North European spearheads with damascened blades. *East NSV Teadusta Akademia Toimetised – ühiskonnateadused/Izvestiya Akademii nauk Estonskoy SSR – obščestvennyye nauki, 1975/2, 171–187. (In German).*

A typological study concerning the pattern-welded spearheads from Estonia (11th–12th centuries AD). The spread of these weapons into Scandinavia, and in the rest of Europe, with the bulk of finds in the East Baltic Area. Results of A. Antein's metallographical analyses quoted.

J Riederer and E Briese. Metal analysis of Roman requisites. *Jahrbuch des Römisch-Germanischen Zentralmuseums Mainz. Jahrgang 1972, 1974,* **19**, *83–88. (In German).*

A great number of bronze objects from everyday life, such as handles, nails, needles, and fish-hooks, were analyzed. It was found that all alloys (which could be produced at that time by fusing copper, tin, zinc and lead) were used. It is remarkable that for different methods of manufacture those alloys were used which had the best properties for working. For handles, formed on the lathe, the same alloys were used as are used today for that purpose. Objects which were produced by casting are rich in lead (which lowered the melting point). Nails and fish-hooks are of materials which could be easily forged. For decorative objects brass with up to 26% zinc was used. JR (AA)

Derek de Solla Price. Gears from the Greeks. The Antikythera mechanism – a calendar computer from ca. 80 BC. *Transactions of the American Philosophical Society, 1974, 64 (7), 1–70.*

The appendix contains the results of qualitative tests on a sample of patina from this mechanism by E R Caley and reports by C S Smith of the results of a spectrographic analysis and ametallographic examination of small fragments of metal. This was found to be a simple tin bronze that had been subjected to intensive cold work. The appendix also contains a note by C Karakalos on the details of the procedure employed in studying the details of this mechanism by radiography. ERC

C E King and R E M Hedges. Analysis of some third century Roman coins for surface silvering and silver percentage of their alloy content. *Archaeometry, 1975,* **16**, *189–200.*

The silver and lead contents of the body and the surface layer of 22 Roman coins dating from the periods of 274 to 294 AD and 294 to 305 AD were determined by X-ray fluorescence. The results are presented as a table which also includes descriptive material on each coin as well as its weight. JSO

Rudolf Kozlowski. Technological examination of a Romanesque chalice and paten from Tyniec, distr. of Cracow. *Acta Archaeologica Carpathica, 1971,* **12** *(1–2), 189–195. (In English).*

Archaeological excavations at the Tyniec abbey led to the discovery of a gold chalice and paten in an abbot's grave (11–12th century) under the floor of the present church. Results of chemical analyses and technical examinations are given. HJ

Wilhelm Holmqvist. Report from Helgö. *Jernkontorets Annaler, 1973,* **157** *(4), 139–146. (In Swedish).*

The archaeological material at Helgö in Sweden was evaluated on the 20th anniversary of the discovery of these early medieval metal workshops. The workshops were large, their development is dated 500–800 AD. Photos of a number of objects are presented. They were made from iron, bronze, and precious metals. Evidence of international trade relations with other countries at that time were seen. MG

G F Carter and W H Carter. Chemical compositions of ten Septimius Severus denarii. *Archaeometry, 1975,* **16** *(2), 201–209.*

10 Septimus Severus denarii minted in the year AD 196 were analyzed by X-ray fluorescence for Cu, Ag, Sn, Pb, Au, Sb, Fe and S. The copper concentrations ranged from 3.6% to 51.7% and the silver concentrations from 47.0% to 59.2%. The coins were slightly ground, polished,and etched and observed with a metallograph. No microstructures are shown but descriptions of the structures observed are given. JSO

Smelting Experiments and their Significance for the Metallurgy of Iron and its History (Schaffhausen 9 – 12 November 1970). *Schaffhausen–Prag 1973. 90 p.. 4 pls. Prepared by W U Gyan, R Pleiner, and Mrs R Fabesova.*

Edited with the help of the Eisenbibliothek – GF Stiftung, Schaffhausen, there appears – after a considerable delay – the first volume of the Comité pour la siderurgie ancienne d'UISPP, containing the papers listed in the summary report on this Conference given in Bull. HMG. 1971, 5 (2), 77–78.

B Boni. Leonardo da Vinci and foundry practice – III. *Founderia Italiana (December, 1973) 22, 361–367. 47 refs. (In Italian).*

Difficulties in contemporary bronze founding arising from the casting of primary metal and remelting antique bronzes of varying compositions were recognised by Leonardo who laid down composition limits for Sn and Pb. Bronzes of the Tuscan renaissance for statuary and artillery had a characteristic composition (Cu88, Sn9, Pb2%) distinct from those of the Roman and Greek–Etruscan periods while bells were cast with about 33% tin to improve sonority. Large statues were produced by welding individual castings. Details of finishing and chemical treatments used for producing a patina are given. MG

I L Barnes, W R Shields, T J Murphy and R H Brill. Isotopic analysis of Laurion lead ores. *In Book: Archaeological Chemistry (Advances in Chemistry). American Chemical Society, Washington, DC, 138, pp 1–10, 1974.*

The lead isotopic ratios of a carefully selected suite of ore samples from the Laurion region were determined by a precise mass spectrometric procedure. The ores were taken from various levels in mines, some known to have been worked in ancient times. All are nearly indistinguishable isotopically within the precision of the method (±0.05%) and they closely match leads from archaeological objects found in Greece. A comparison with isotopic data for ores from other mining regions in the ancient world has been made. The uniformity of the Laurion ores facilitates the interpretation of lead isotope data for archaeological objects from Greece. AA

Jerzy Wielowiejski. The development of metal casting technique in ancient Greece. *Kwartalnik Historii Kultury Materialnej, 22, No.3, pp 393–423 (1974). 24 Illus., bibliography. French summary (In Polish).*

A detailed study on historical development and techniques of casting is presented, based on archaeological and other sources. HJ

Peter Hammer and Heinz Klemm. Piece of bloomery iron from Tannenberg in the Erzgebirge. *Neue Huette, 1974 (4), 241–243. (In German).*

In 1967 a large, compact piece of Fe, weighing 1532 kg was unearthed. It was at first thought to be a meteorite, but micro examination and wet chemical analysis of cuttings resulting from sawing the piece in half gave C 0.1, Si 0.11, Mn 0.02, P 0.244, S 0.022, Cr 0.03 and V 0.06% with an absence of Ni, Mo, Co and W proving otherwise. The composition varied considerably in different sections, and as high as 2.2% C was found locally. The structure was about 80% ferritic. There were inclusions of slag, consisting of oxides and silicates of Fe. It was concluded that this was a piece of bloomery Fe made in the middle ages.

W Menghin. The grave of a Langobard warrior in the National Museum, Nürnberg. *Archäologischer Korrespondenzblatt, 1974/3, 4, 251–256.*

Pattern-welded blade (alternating stripes and twistings) of a spatha from the so-called Warrior's grave of Milano, mid-seventh century AD.

G A Voznesenskaya. Metallographic investigations of forgings from early Slav sites. *Kratkiye soobšeniya (Moskva), 1967, (110) 124–127. (In Russian).*

Metallographic examination of five early Slav knives and one sickle from the sites of Korčak 7, and Teterevka I (6th–7th centuries AD). Welded-on steel edges, quenched: the sickle was an all-steel implement.

R Wyss. The economy and trade in the pre- and early historic archaeology of Switzerland III. *The Bronze Age. Basel 1971 (In German).*

G E Arešyan. The Earliest centres of iron metallurgy in western Asia and eastern Mediterranean. *Vestnik Yerevanskogo universiteta, 1974 (3), 124–138. (In Russian).*

The author discusses ancient legends concerned with iron metallurgy. He further deals with the geography of ethnic and topic names related to the Chalybes and Chaldeans, whose territory reached in his view, up to northwestern Armenia or Colchis.

P Eichhorn et al. Research on bronze inlays for iron in the Hallstatt period. *Fundberichte aus Baden-Württemberg 1. 1974, 243–298. (In German).*

Some late Hallstatt period ornamented iron objects (eg. wheel-naves, belt sheets, dagger hilts) used to be incised, tinned, equipped with bronze inlays and then sealed with clay, and heated in a charcoal fire. Molten bronze inlays were extremely well joined to the iron matrix. Fluorescent, microprobe, and metallographical analyses.

M Čičikova. Research on the Thracian Early Iron Age civilisation. *Archeologiya (Sofia), 1974/4, 19–27. (In Bugarian).*

Oldest iron swords of the Naue II type might be contemporary with those from Kerameikos or Agora at Athens. Unfortunately, the five specimens are not stratified.

J Ziomecki. Artisan manufacturing techniques in Athens in the light of vase-paintings from the 6th and 5th centuries BC. *Archeologia, 1973, 24, 50–73 (Warszawa-Wrocaw-Kraków-Gdańsk). (In Polish).*

Discussion on 36 Greek vase paintings depicting various handicrafts. Among these, the potter's work is best represented; whereas paintings with other crafts are content with certain stereotypes (workshop of Hephaestus in the case of metal workers or blacksmiths).

W Hübener. The Roman metal finds of Augsburg-Oberhausen. *The Catalogue Materialhefte zur bayerischen Vorgeschichte 28. Kallmünz/Opf. 1973. (In German).*

The above locality used to be called a castel in spite of the total shortage of documentation. Differing interpretations of this early Roman rich assemblage are possible. Among about 100 kinds of iron objects there also appear blacksmith's tools (anvils, hammers, tongs, cf. pl. 18, 19).

ASIA

Masanobu Sakanoue. Radioactivation analysis of the gilding of the Great Buddha of the Todaiji temple, and of the lead tile of the Ishikawa gate, Kanazawa castle. *Kokogaku-To-Shizen Kagaku (Archaeology and Natural Science) December, 1974 (7), 9–17. (In Japanese).*

Detection of mercury by radioactivation analysis confirmed the use of gold amalgam for gilding at the time of the construction of the Great Buddha at Todaiji temple in Nara in the 8th century. Silver, antimony, manganese and copper were detected in the lead roofing tile. The content of silver was estimated to be 0.074%.
KY

Pieter Meyers, Lambertus Van Zelst and Edward V Sayre. Major and trace elements in Sasanian silver. *In Book: Archaeological Chemistry (Advances in Chemistry). American Chemical Society, Washington DC, 1974,* 138, *22–23.*

Small samples from Sasanian silver objects were analyzed by thermal neutron activation analysis to determine the concentrations of three major elements, Ag, Cu and Au and 16 trace elements, Na, K, Sc, Cr, Mn, Fe, Ni, Co, Zn, As, Br, Sn, Sb, Se, Ir, and Hg. Two micro sampling techniques (drilling and rubbing) were used for Ag, Cu and Au. Analyses for major components in rubbing and drilling samples of the same objects showed the effects of surface enrichment for gold and surface depletion for copper. Drilling samples of ca. 500μg were used to determine trace element concentrations. Multiplicate analyses were satisfactorily reproducible in the silver-alloy for Ir, Zn, Se, As and Sb, less satisfactory for Sn, Sc, Mn and Br while large inhomogeneities were observed for Cr, Ni, Fe, Co, Hg, Na and K. Objects were grouped according to trace element compositions in order to relate such groups to art historical information. So far gold and iridium concentrations seem to be the most promising criteria for distinguishing different origins of silver ore.
AA

Yukio Matsushita. Restoration of the Tatara ironmaking process and ancient ironmaking process of Japan. *Proc. Int. Conf. Sci. Technol. Iron Steel, 1970 (1), 212–218. (In English).*

The construction and operation of the ancient Tartara furnace for production of iron and steel and metallurgical data on the process and products are presented. Three experimental heats were produced and tested by metallographic chemical and mechanical analyses and for forge-weldability. A movie record was made of the entire process, from the construction of the furnace to the production of the reduced metal.

Rikuo Ishikawa and Kenzo Toishi. Identification of bronzes through scientific methods. *Kokogaku Zasshi, (J. Archaeological Soc. Nippon), December 1973* 59 *(3), 263–266. (In Japanese).*

X-ray radiographic results on a stirrup of gilt bronze, (Miyajidake shrine), and an Iranian copper halberd; and metallographic results on a fragment of a copper arrowhead are described. The stirrup was made by combination of cast parts, and the halberd solely by casting. The arrowhead was made by hammering the cast rod.
KY

D L Giles and E P Kuijpers. Stratiform copper deposit, northern Anatolia, Turkey: evidence for Early Bronze I (2800 BC) mining activity. *Science, November 29, 1974* 186 *(4166), 823–825.*

A copper sulfide deposit found at Kozlu in north central Anatolia in 1972 had wood rubble associated with it which gave a carbon-14 date of about 2800 BC and which may have been remnant mining timber. In 1973 a large copper casting which appears to be partially refined molten ore (copper matte, ie. melted metallic sulfide mixture) was found 3 miles from Kozlu.
EWF

V D Len'kov. Metallurgy and metal working of the Choorchians in the 12th century AD. *Novosibirsk, 1974, 171 pp., 3 pls. (In Russian).*

An interesting account of discoveries in the Central Amur region and in the adjacent part of Manchooria (Choorchian realm of the 12th/13th centuries). Excavations of the hill fort at Sayginskoye brought to light many foundries and blacksmith's workshops equipped with various types of brick and stone built installations for forging and casting iron. Blacksmith's tools, analyses of bricks, slags, iron; metallographic analyses of knives, axes, chisels etc (wrought iron, steel, also steel-to-iron-welding, tempering). White, or grey cast iron (kettles, plough-shares). The smelting of iron is presupposed outside of Sayginskoye, in the region of Udaolin, near to ore deposits, where furnaces of several different types have been discovered.

J A Voznesenskaya. Technology of iron objects from the cemetery of Tli. *In: Očerki technolgii drevneyšikh proizvodstv, Moskva, 1975, 76–116. (In Russian).*

An important study presenting metallographical analyses of a large set of 100 iron artifacts from the assemblage found at the Caucasian cemetery of Tli, dating from the earliest Iron Age. 16 specimens from the 9th–8th century (secondary carburizing, rarely faggoted metal, sporadic occurrence of heat treatment). The rest of artifacts dates into the 7th–6th century (Scythian period: carburizing, piling, some iron-to-steel-welding, heat treatment). Complete descriptions of individual analyses accompany the report. It is to be regretted that chemical analyses are missing.

UY F Buryakov. Mining and metallurgy of the Medieval Ilak. *Moskva 1974. (In Russian).*

In the regions north of Amu-Darya and in Central Asia iron and copper was less important than the exploitation of silver, lead and gold. Research on ore mines dating from the 5th to 16th centuries AD.

M Tadmor. Fragments of an Archaemenid Throne from Samaria. *Israel Exploration Journal (1974), 24 (1), 37–43. (In English).*

The paper deals with three fragments (exhibited in the Israel Museum) which belonged apparently to the bronze casing of a throne dating to the Persian Period (538–332 BC). After detailed description and stylistic analysis, the author suggests a reconstruction. The technique of the casting and the nature of the alloy are based on results of X-ray testing and thermal neutron radiography (by the Non-Destructive Testing Laboratory in the Soreq Nuclear Research Center), and chemical analysis of metals and trace elements analysis of the cores by emission spectrography (by the geochemical division of the Geological Survey of Israel).

MIB

AFRICA

H White and G St J Oxley Oxland. Ancient metallurgical practices in the Roolberg area. *Journal of the South African Institute of Mining and Metallurgy, January 1974* **74** *(6), 269–279. (In English).*

Some notes are given on evidence of early metallurgical activity in this area. Evidence of Cu smelting and of the production of brass and bronze has been found but is fragmentary and direct evidence of tin production is lacking.

MG

B H Sandelowsky. Prehistoric metal-working in South-West Africa. *Journal of the South African Institute of Mining and Metallurgy, May 1974,* **74** *(10), 363–366. (In English).*

An account is given of an investigation of a metal-working site at Rehoboth, near Windhoek. Surface evidence of slags, charcoal, ash, and heat affected stones and sand led to excavation from which stone objects identified as tuyeres were recorded. It is concluded that the site dates from about about AD 1650 and represents the use of a different technique to that employed in South-Central and East Africa. The essential difference is that this site indicates a furnace consisting of a hole in the ground using a stone tuyere, while in the other areas low clay shaft furnaces and clay tuyeres were used. The implications are discussed.

MG

M D Prendergast. Research into the ferrous metallurgy of Rhodesian Iron Age societies. *Journal of South African Institute of Mining Metallurgy, 1974,* **74** *(6), 254–264. (In English).*

Minimal historical and metallurgical investigations in Iron Age Rhodesia exist. The available evidence and its interpretations were presented. Suggestions are made for further research.

M Klapwijk. An analysis of Bantu-made iron implements from the Letaba district. *Journal of the South African Institute of Mining and Metallurgy, January 1974,* **74** *(6), 268–269.*

A detailed analysis is given of the shape and dimensions of 585 iron implements collected in the Letaba district of the Transvaal. It is concluded that a recognizable form of implement typical of the area exists but it is uncertain that the iron used was of native manufacture.

MG

M E Dingle, J Stanko and D D Howat. An attempt to smelt iron in a Buispoort type of furnace. *Journal of the South African Institute of Mining and Metallurgy. January, 1974,* **74** *(6), 268–269.*

A series of experiments is reported with a furnace modelled on a museum example of a native (South African) furnace. It was possible to produce small pieces of forgeable iron but only with great difficulty.

MG

AMERICA

Jean Trudel. Study of a silver statue by Salomon Marion. *The National Gallery of Canada Bulletin 1973 (21), 3–21. 17 illus., 3 diagrams, 2 tables, Eng. summary. (In French).*

A silver statue, 50.5 cm high, was made in 1818 by Salomon Marion, a silversmith in Montreal. The figure, representing the Virgin Mary, is constructed ingeniously of nine formed silver plates. The clasped hands are the only part in solid silver. Analyses by EDX (energy dispersive X-ray) indicate that the percentages of silver range from 96.9 to 90.5 with small traces of Pb, Au and Zn. The author explores also the historical significance of Salomon Marion's work as related to silver-smithing in the tradition of the early days of New France.

MR

R M Meyers and J F Hanlan. The compositional analysis of French-Canadian church silver. *The National Gallerv of Canada Bulletin, 1973 (21), 22–33. illus., 3 diagrams, 3 tables, French summary.*

Analyses of items of church silver dating from 1760 were carried out by means of energy dispersive X-ray equipment. As no original Canadian silver was available at that time, all articles were made from remelted silver objects, coins and scrap. The results of the analyses performed by the authors show that the silver was generally of high quality. A chronological table accompanying the account lists works of silversmiths that were tested. Percentages indicate that the silver content ranged from 97.7 to 92.2 with Pb, Au, As and Zn appearing as trace elements.

MR

SCIENTIFIC EXAMINATION

F N Tavadze and others. Investigation of archaeological iron studied by the electron microprobe technique. *Soobshch. Akad. Nauk Gruz. SSR. 1974,* **74** *(2), 389–391. (In Georgian).*

Local X-ray diffraction analysis of archaeological Fe specimens dated 100 BC showed the presence of a matrix of technically pure Fe with slag-oxide inclusions.

D F Gibbons, K C Ruhl and L S Staikoff. Analysis of Sasanian silver objects; a comparison of techniques. *In Book: Archaeological Chemistry (Advances in Chemistry), American Chemical Society, Washington DC 1974,* **138**, *11–21.*

Data were obtained to demonstrate whether the metallurgical structure affected the accuracy with which copper, gold and lead concentrations could be determined on small samples ($<$1 gram) from ancient silver specimens. The data were taken from objects mainly assigned to the Sasanian period. Analytical methods included X-ray fluorescence, electron microprobe, and thermal neutron activiation analyses. The data demonstrated that the accuracy is directly related to the uniformity of the metallographic structure. Surface sampling techniques tend to under-estimate the copper concentration, and care must be taken in interpreting gold analyses from surface rubbing techniques to ensure that the object had not previously been gilded. Emission spectroscopic analyses tend to overestimate the lead concentration.

AA

J C Chaston. Wear resistance of gold alloys for coinage — an early example of contract research. *Gold Bulletin. October 1974, 7 (4), 108–112.*

This paper describes an investigation into the wear of gold coinage which was initiated in 1798. The initial approach was to investigate the physical properties of 13 alloys of gold, each of which contained 2 carats of another element. Experiments with a specially constructed wear-testing machine were carried out in which both coins and coin blanks of the same and different metals were rubbed on one another.

The conclusions of the work were that the 22 carat gold alloy then in use should not be changed. WAO

W T Chase. Comparative analysis of archaeological bronzes. *In Book. Archaeological Chemistry (Advances in Chemistry), American Chemical Society, Washington DC (1974),* **138,** *148–185.*

While thousands of analyses of archaeological bronzes have been reported in the literature, the basis for comparing them, especially those from different laboratories, is shaky. A round-robin project of chemical analyses was attempted to improve the situation. Two ancient bronze objects were milled to a fine powder, sieved and mixed to a homogeneous mass. Samples of 500 mg each drawn randomly from this mass were circulated, and results were returned from 21 laboratories. Forty-eight elements were analyzed; some laboratories did only one element, some did as many as 42. The coefficient of variance (or relative standard deviation) ranges from 4% for Cu up to over 200% for some trace elements.

The results are tabulated, and methods are suggested to narrow the spread of results in the next run of this program. AA.

TECHNIQUES

D L Carroll. A classification for granulation in ancient metalwork. *American Journal of Archaeology. 1974,* **78** *(1), 33–39.*

This article deals extensively with the history of the granulation, the materials needed, the various techniques employed to accomplish it, and the mechanisms that govern the interrelationship among the grains and between the grains as a predetermined pattern to the metal surface. Granulation is a complex form of jewelry decoration that often goes with metal-working of a high level. It can be an indication of the degree of sophistication reached by a culture in a particular area. TS

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