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Platinum Group metal inclusions in Ancient Gold Artifacts

Jack M Ogden ©

Abstract

Inclusions, comprising grains of natural alloys of the platinum group of metals, have been noted in ancient goldwork since last century but it is only recently that any systematic study has been possible. Such a study has largely depended on the development of the electron microprobe and related techniques and the rapidly growing body of information on the mineralogy and distribution of natural platinum group metal grains in world-wide placer deposits. The extreme commoness of such placer platinoids and the frequency with which platinoid inclusions occur in ancient goldwork make any chance of source correlation remote but the actual presence and arrangement of the inclusions within an item of gold can give valuable information regarding the extractive and manufacturing techniques used in antiquity. The paper includes some new analyses of inclusions from ancient goldwork, a survey of Old World platinum group metal sources and discusses whether or not early people were aware of the platinum group metals.

Introduction

Continuing advances in analytical techniques are rapidly increasing our knowledge of the trace elements in ancient artifacts, elements that can sometimes act as guides to the sources of the raw materials and the working processes to which they were subjected. Of the variety of trace elements in early gold items particularly persistant are small amounts of the platinum group metals – platinum, palladium, osmium, iridium, ruthenium and rhodium (Table 1). These platinum group elements (PGE) can be present in gold artifacts in what is essentially solid solution (although sub-microscopic inhomogenities probably exist [1])or else take the form of small greyish-white inclusions in the gold which are usually visible under the microscope if not to the naked eye. These visible inclusions are the subject of this paper.

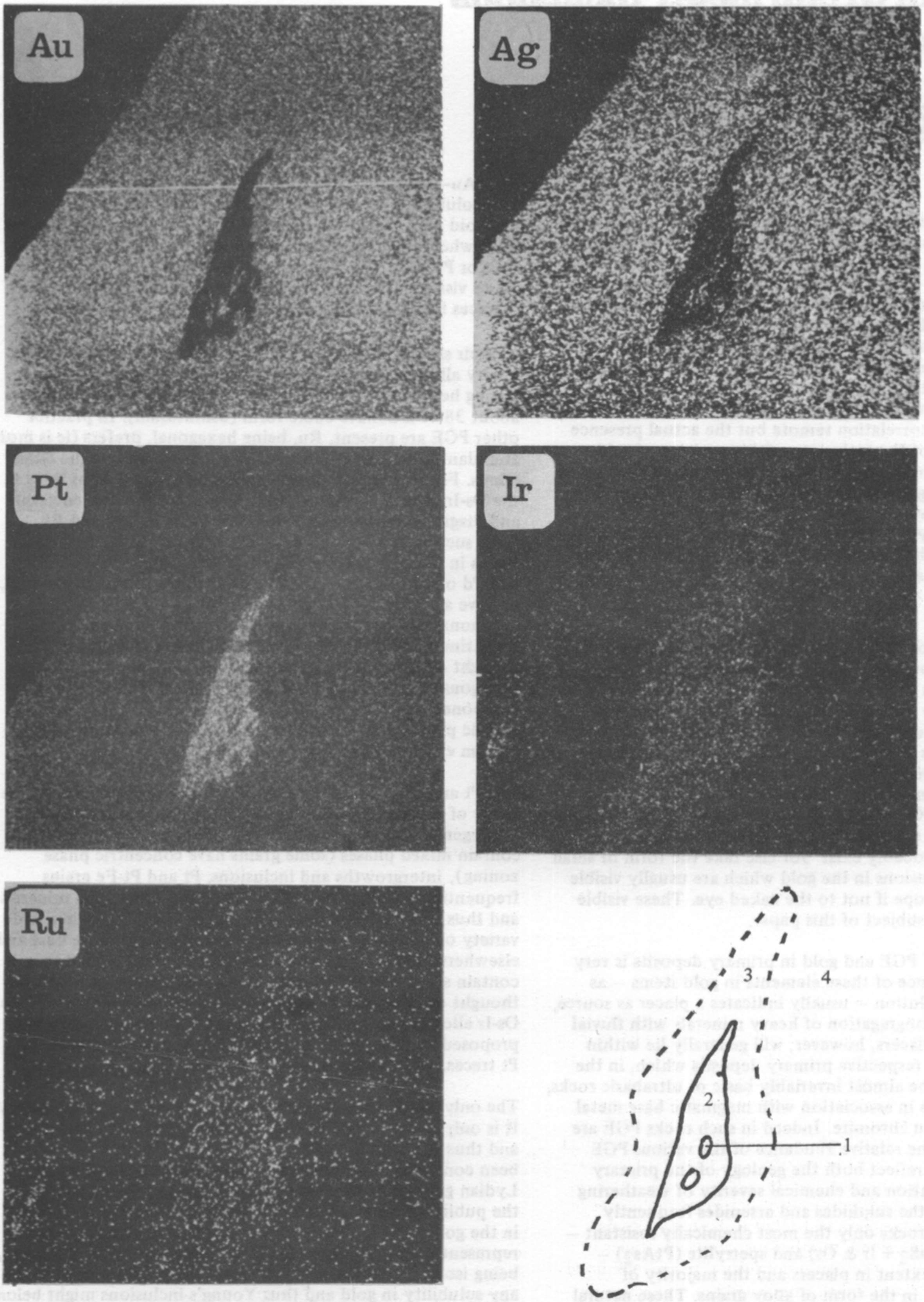
The association of PGE and gold in primary deposits is very rare and the presence of these elements in gold items – as inclusions or in solution – usually indicates a placer as source, the result of the congregation of heavy minerals with fluvial transport. These placers, however, will generally lie within a few miles of the respective primary deposits which, in the case of PGE, will be almost invariably basic or ultrabasic rocks, frequently olivines in association with magmatic base metal sulphides and often chromite. Indeed in such rocks PGE are usually present. The relative abudance of the various PGE in the placers will reflect both the geology of the primary rocks and the duration and chemical severity of weathering and transport. Of the sulphides and arsenides frequently found in the host rocks only the most chemically resistant – such as laurite (RuS_2 + Ir & Os) and sperrylite ($PtAs_2$) – are found to any extent in placers and the majority of PGE in placers are in the form of alloy grains. These natural alloys of PGE are termed platinoid grains – although Pt itself might be absent.

The high specific gravities and chemical inertness of the platinoid grains that resulted in their congregation with the gold in the placers also means that they will pass with the gold through most recovery and sorting processes and be present when the gold is melted. As the platinoid grains have melting temperatures in excess of that of gold (including the usual Au–Ag–Cu alloys) their behaviour largely depends on their solubilities in gold. For the sake of convenience the platinoid grains can be considered to lie in one of two groups, those where Os + Ir predominate and those that are essentially of Pt or Pt + Fe. The former are insoluble in gold thus giving rise to visible inclusions, the later are soluble hence the Pt traces in many categories of ancient gold items.

In their simplest form the insoluble grains are represented by binary alloys of Os and Ir, those with over about 55 at % Os having hexagonal structure (iridosmine) and those with under about 38 at %Oshave cubic form (osmiridium). In practice other PGE are present, Ru, being hexagonal, prefers (ie is most abundant in) the hexagonal alloys whilst Pt prefers the cubic alloys. For this reason the grains can be thought of as lying in the Os-Ir–Ru or Os–Ir–Pt ternary systems the nomenclature and diagrams for which are shown in table 2.[2] Pd and Rh (plus such metals as Cu, Fe, Ni, Au etc) can occur in small traces in these alloys. Despite their cubic symmetry both Rh and Pd often seem, on the basis of analyses of placer material, to have an 'affinity' for Ru and be most abundant in the hexagonal and particularly the rutheniridosmine alloys. Sometimes Ru>Os in the hexagonal alloys but Ru can still be thought of as replacing Os, indeed with the majority of hexagonal alloys the ratio of the hexagonal to the cubic components is fairly constant at about 3:2 (in terms of atomic proportions). Pt can be thought of as replacing Ir but seldom exceeds 10 at % Ir + Os + Pt.

The Pt and Pt–Fe grains, being soluble in gold are outside the scope of this paper but, as with platinoid grains in general, homogenity can never be assumed and individual grains often contain mixed phases (some grains have concentric phase zoning), intergrowths and inclusions. Pt and Pt-Fe grains frequently contain inclusions of Os-Ir and other PGE minerals and thus, whilst Pt has been detected in small traces in a wide variety of ancient goldwork from Europe, the Middle East and elsewhere,many of these items might also be expected to contain some visible platinoid inclusions. Even placers usually thought of as mainly Pt producers will normally contain some Os-Ir alloy grains – an example is the Rhine which is often proposed as a source of some of the European goldwork with Pt traces.

The only alloys not so far mentioned are the binary Pt-Ir alloys. It is only recently that the homogenity of such natural alloys and thus the existence of a mineral species 'platiniridium' has been confirmed[3]. According to Young inclusions in some Lydian gold coins were composed of about 60% Pt, 40% Ir[4]; the published photos show no evidence for partial diffusion in the gold. Pt–Ir alloy grains can probably be considered to represent either Pt containing Ir or Ir containing Pt, the latter, being isomorphous with Ir would probably have limited if any solubility in gold and thus Young's inclusions might belong here. That Pt–Ir alloys with compositions lying nearer the Pt end of the system are partially soluble in gold is shown by the writer's experiments in adding grains of a nominal 90% Pt, 10% Ir commercial alloy to molten gold (Figure 1). Ir does have a very small degree of solubility in gold (Table 1) and has been used in recent years as a grain refiner in some dental alloys (not without causing segregation problems) but the present writer knows of no other published parallels to the trace of Ir found in a Minoan gold axe.[5]



	Au	Ag	Pt	Ir	Ru	Rh
1	41.1	3.7	22.1	5.2	0.6	0.4
2	0.9	0.2	89.1	4.9	0.8	0.6
3	67.2	8.2	9.5	9.0	1.9	0.6
4	81.1	10.2	5.9	0.2	0.0	0.0

Weight %

THE DIFFUSION OF A NOMINAL 90% Pt, 10% Ir GRAIN (US COMMERCIAL ALLOY) IN A GRANULE OF GOLD FUSED IN A BLOW–PIPE FLAME.

Figure 1

Element	Symbol	At. wt.	Crystal Structure	Lattice	mp.°C	SG	Extent of solid solution in Au
Platinum	Pt	195.09	fcc	3.9158	1769	21.45	Generally believed to form a continuous series of solid solutions in Au but the formation of two phases in Au/Pt alloys is well known and submicroscopic inhomogenities have been found in Au/Pt/Pd dental alloys
Palladium	Pd	106.4	fcc	3.8824	1552	12.02	
Osmium	Os	190.2	cph	a.2.7298	3050	22.61	Negligibly small
Iridium	Ir	192.2	fcc	3.8312	2443	22.65	Very small. Under ordinary conditions the limit of solid solution is <0.12%, this has led to segregation problems with dental alloys which have had Ir added as a grain refiner
Ruthenium	Ru	101.07	cph	a 2.6984 c 4.2730	2310	12.45	Negligibly small, probably < 0.5%
Rhodium	Rh	102.91	fcc	3.7957	1960	12.41	Small, probably<0.6%

THE PLATINUM GROUP METALS

Literature on the solubility of PGE includes G V Raynor 'The alloying behaviour of Gold' **Gold Bulletin** 1976, 9 (1), 12–19. and M Hansen **The constitution of binary alloys** 2nd edition 1958 and 1st supplement.
The melting temperatures and specific gravities, which differ in some respects from generally quoted values, are taken from **Platinum metals review** 1963, 7 (4).

TABLE 1

The inclusions in goldwork

From what has been said regarding the natural occurrence and solubilities of platinoid grains in gold it is to be expected that most visible inclusions in ancient gold items will be alloys with Os + Ir predominating and basically either Os + Ir + Ru or Ic + Ir + Pt. Petrie was thus probably correct when he reported inclusions of an Os-Ir alloy in Egyptian goldwork[6] although later writers referring to Egyptian gold were more cautious in their identifications[7] and Lucas even doubted Petrie's view in favour of platinum itself – far less likely on metallurgical grounds. Most published mentions of platinoid inclusions in ancient goldwork have been restricted to Egyptian items although Caskey described 'numberous minute particles of white metal – platinum or osmium-iridium' in a Greek bowl of 7th century BC[8] and Smith found whitish inclusions in Sumerian goldwork but, although toying with the idea that these could be 'particles of platinferous material' (now found to be correct – publication forthcoming), he finally attributed them to solder splashes[9] surprising in view of his extensive knowledge of the noble metals.

With the relatively recent development of the electron microprobe and related techniques it has been possible to identify accurately the inclusions **in situ** in a gold matrix. The earliest analyses along these lines include the work of Young[10] and the unpublished report of the sectioning of an Egyptian gold button at the laboratories of Johnson, Matthey & Co Ltd which mentions small 'angular surface inclusions' of a bluish grey colour which contained Os, Ir, Rh and Ru.[11] Over the last few years the present writer has instigated some further analyses[12] and has prompted an interest in various quarters that is resulting in a fuller analytical programme.

Even cursory microscopic examination of ancient goldwork soon shows that platinoid inclusions are extremely common and, in many categories of item, are more often than not present. So far there is no information regarding Egyptian Old Kingdom and First Intermediate Period goldwork, but platinoid inclusions occur in the major proportion of Egyptian goldwork from the 12th Dynasty onwards, including Roman and Byzantine items.[13] They are also common in much Western Asiatic goldwork from the earliest times right through Hittite, Archaemenian, Sasanian, Roman, Byzantine and even later periods. Examples include gold from the Ur Royal Tombs, pieces from Brak, Tel Omar, the Oxus Treasure and even goldwork of recent centuries from Iran. Goldwork from Cyprus of Hellenistic and earlier date also contain visible platinoid inclusions but so far they have not been found in Trojan goldwork.

There is far less information regarding European goldwork with platinoid inclusions despite the wealth of analyses of Prehistoric items with traces of Pt in solution in the gold[14] Inclusions are quite common in Greek goldwork (including some coins – Figure 2) but few of the pieces can be attributed to the Greek mainland rather than elsewhere in the Mediterranean area. The same is true of Roman jewellery although one certain instance is a buckle end from Hungary. The present writer's examination of Roman goldwork from Britain has found no trace of platinoid inclusions but the gold usually seems to be of exceptionally high purity (see for example Henig and Ogden[15]) this could indicate the use of coinage as the raw material for the jewellery and in turn efficient refining (see below). Analyses 4 and 5 in Table 5 are of a platinoid inclusion in a European Dark Age garnet set gold brooch.[16] Platinoid inclusions seem fairly common in English gold jewellery of the 16th-18th century AD and, of course, at this period a South American origin is possible. The general frequency of platinoid inclusions in ancient, and even more recent, goldwork does show the extent to which gold was obtained from alluvial sources.

The extreme commoness of PGE association with gold in placers and the difficulties experienced in separating platinum group metals from gold by mechanical or chemical methods means that platinoid inclusions have occurred in recent gold. They were common in the last century in gold ingots, jewellery and coins. Eissler describes them as 'of vexatious annoyance to the manufacture of jewellery',[17] thus mirroring Dana's earlier comments regarding the platinoid content of Californian gold[18] whilst Riemsdyk remarked that 'la plupart des pieces monnayees contiennent des quantitées notables de metaux platiniques, probablement sous la forme d'osmiure d'iridium'[19]. Even at the present time in Europe and elsewhere some platinoid inclusions are found in commercial gold items (examples include a wedding ring recently seen by the writer). One possible cause is the insufficient refining of some of the South African gold that contains PGE. Some of this gold is refined at the Rand refineries, S. Africa, to 99.5% by the chlorination process alone which has little effect on associated platinoids. These 'good delivery' bars have sometimes been finding their way direct to manufacturing workshops rather than as intended being sent to other worldwide refiners for electrolytic re-refining and redistribution.[20] There is also the possibility of some PGE entering modern gold due to the recyclying, without proper refining, of such articles as gold pen nibs with platinoid tips (natural Os-Ir alloys were long used for this purpose but nowadays such alloys as Ru with a little Pt are increasingly used) or dental alloys and jewellery containing PGE. Despite Williams's suggestion that platinoid inclusions are useful criteria in considerations regarding the authenticity of ancient goldwork[21] (ie. analysis 7 in Table 5) there is no evidence that they are deliberate additions by astute forgers. This could reflect local exploitation of native gold – for example according to reports there is still some small scale gold panning by local peasants in Turkey – or the recycling of damaged ancient gold items.

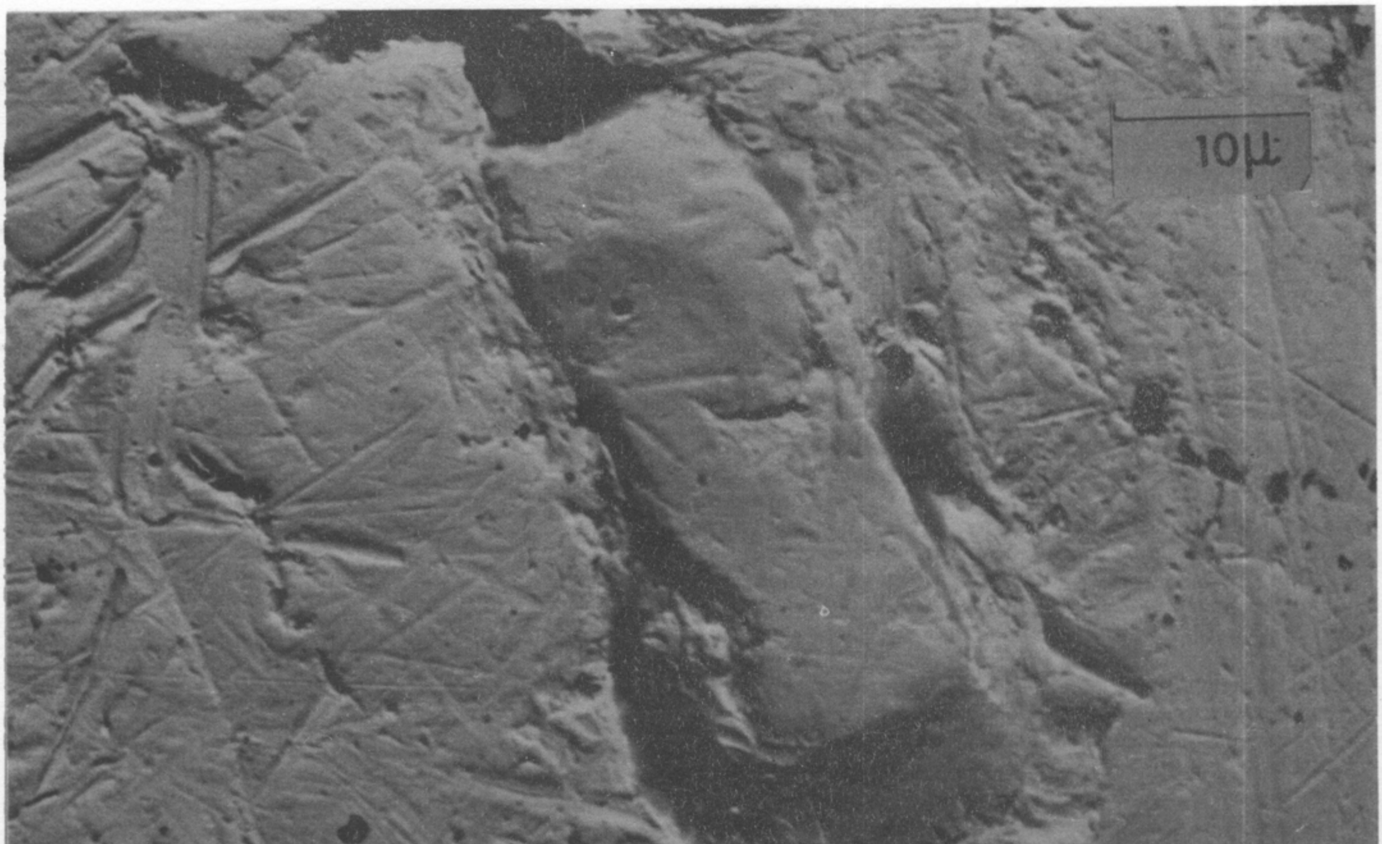


Figure 2 A tabular inclusion in a gold stater of Philip of Macedon (c.350 BC). Qualitative analysis by XRF gave an approximate composition of Ru > Os > Ir hence the inclusion would be rutheniridosmine.

Name	Compositions	Crystal form	Colour	Hardness in H_v	Approx SG	Recorded as inclusions in goldwork
Osmium	Os>80 at%	cph	bluish grey	1200	22.6	Not so far
Iridium	Ir>80 at%	fcc	silvery white	500 – 600?	22.6	Not so far (analysis No 2 in table 5 comes close)
Iridosmine	Os 55-80 at% of Os+Ir. No other element >10 at%	cph	bluish grey	750 – 950	22.6	Frequent. Exx analyses 3 & 7 in table 5.
Osmiridium	Ir 62-80 at% Os+Ir. No other element>10 at%	fcc	cream or rosy white	650 – 800	22.6	Quite frequent. Exx analyses 1, 2, 4, 7 and 9 in table 4 and No 2 in table 5.
Rutheniridosmine	Ru 10 – 80 at% Os+Ir+Ru. Os <80 at% Os+Ir+ Ru and Ir <45 at% Os+Ir+Ru No other element >10 at%	cph	bluish grey	900 – 1000	13 - 22	Very frequent, exx analyses, 1, 4, 5 & 6 in table 5 The frequency is largely explained by the huge rutheniridosmine field as defined in the ternary diagram as seen below (Table 2b). Subdivision of this field on mineralogical characteristics is not possible so far.
Platiniridium	Pt+Ir> 80 at%	fcc	white to silvery	150 – 250'	22	Reported by W J Young, see text

THE NOMENCLATURE OF NATURALLY OCCURRING PLACER PLATINOID ALLOY MINERALS

Note: Occasional instances of ruthenian osmium, osmian ruthenium and iridian ruthenium have been recorded from placers but have not so far been found as inclusions in goldwork. Ruthenium (ie alloys with Ru>80 at%) and ruthenosmiridium have not yet been recorded in nature.

The Pt–Ir alloys need further study to see if a distinction should be made between platiniridium and iridian platinum and, if so, where the boundary should lie.

TABLE 2a

Ternary diagram showing the Os-Ir-Ru system and part of the Os-Ir-Pt system. Most of the platinoid inclusions in ancient gold can be plotted in this diagram.

Adapted from Harris & Cabri (1973)

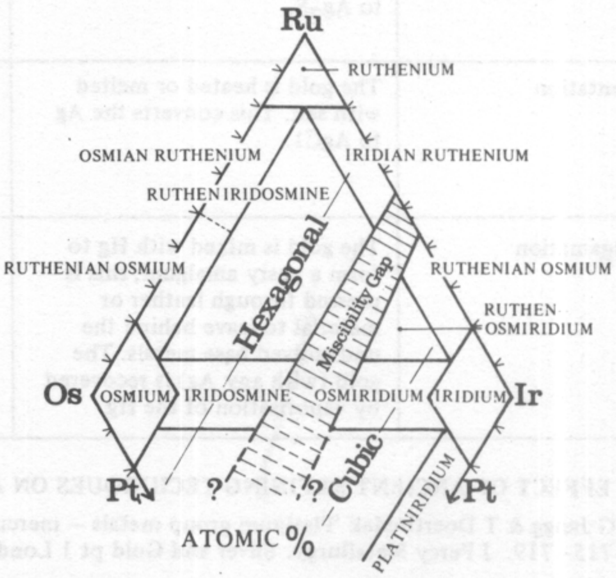


TABLE 2b

The inclusions seen in ancient goldwork vary from rounded to angular (often tabular) or irregular forms. Some are clearly subhedral or euhedral and inclusions of distinct hexagonal shape – hence iridosmine or rutheniridosmine – are quite frequent. The largest recorded inclusion was one of 3mm in length seen in a Greek bowl[22], the largest noted by the present writer was barely 1mm long. Many lie in the 50–150μm range whilst some are so minute that they can only be seen in polished gold sections at high magnifications. The platinoid inclusions in gold generally compare in size and shape to the grains found in the placers having undergone little change during the retrieval and gold working processes but some fragmentation of inclusions is found in items that were subjected to severe hammering during manufacture.

Most of the inclusions visible on the surface of ancient gold items have a bluish or steely grey colour. This is most characteristic of hexagonal iridosmine or rutheniridosmine; the darker the colour the higher the Os content in theory but in practice the leaching effects of fluvial transport and various goldworking procedures can darken the colour of the grains and colour differences are generally only seen after polishing. The characteristic colours of the various platinoid grains are shown in Table 2. Often bluey-grey inclusions – representing hexagonal phases – and creamy or rosy coloured cubic phases (sometimes almost blending with the surrounding gold matrix) are seen in a single item after sectioning and polishing. This tentative distinction between hexagonal and cubic phases by colour is usually supported by their respective reflectivities – the Ir rich alloys appear far brighter – and their polishing hardnesses as shown by their relief against the gold. The hardness of Os-Ir alloys increases with Os and/or Ru content. Microhardnesses of various platinoid alloy grains (taken from the literature) are shown in Table 2 but should only be taken as a rough guide, as the work-hardening or annealing effects of fluvial transport or goldworking processes are uncertain. Other properties of platinoid grains – such as magnetism – are sometimes detectable in inclusions in goldwork.

Visual estimation of PGE content in gold artifacts is difficult, a single item might contain a single isolated inclusion or a measle-like profusion. Sometimes most of the inclusions in an item will be grouped in a single rash-like patch. In quantitative terms the PGE are usually present in fairly small amounts, a single visible inclusion in say a coin can reflect a PGE content of under 1ppm whilst even the most infested gold item seen by the writer can hardly have contained much more than a few tenths of a percent PGE. It is unlikely that any gold object would have a high enough platinoid content to have a significant effect on determinations of composition based on specific gravity measurement.

The effect of platinoid inclusions on goldworking processes

For as long as forms of gravity sorting – panning, sluicing, etc – have been used to collect placer gold any associated platinoid grains would have been recovered with the gold but it is possible that in the earliest periods and/or amongst primitive peoples, some gold would have been collected by simple hand sorting. This would seldom result in the recovery of associated platinoids and might explain the lack of PGE traces in some of the earliest goldwork from Europe and elsewhere.

NAME	PROCESS	EFFECT ON PLATINOID PRESENCE
Cupellation	The gold is melted with lead, base metals oxidise.	Pt, Pd and Rh dissolve in Au/Pb alloys, Os, Ir and Ru do not. At high cupellation temperatures some Os could be vaporised and a lessening of PGE presence is possible but at normal cupellation temperatures (about 1063°C) platinoid inclusions are not removed from gold (or silver).
Sulphide process	The gold is heated with a sulphide to convert the Ag to Ag_2S.	Pt itself is not removed from gold alloys by sulphide refining methods and the same is likely to be ture for Os, Ir, Ru etc. Platinoid inclusions certainly remain in gold alloys subjected to a H_2SO_4 parting process.
Cementation	The gold is heated or melted with salt. This converts the Ag to AgC1.	Platinoid association with gold is not affected by the modern chlorination refining process and experiments suggest that at lower temperatures the ancient salt method would have had little effect but over about 650°C some PGE are attacked by C1.
Amalgamation	The gold is mixed with Hg to form a pasty amalgum, this is pressed through leather or material to leave behind the undissolved base metals. The gold (with any Ag) is recovered by vaporisation of the Hg.	Pt is slightly soluble in Hg but Os, Ir, Ru and their alloys are almost insoluble ($<10^{-5}$%) and, depending on the pore size of the straining medium, would be separated from the gold.

THE EFFECT OF ANCIENT REFINING TECHNIQUES ON ASSOCIATED PLATINOIDS.

See: G Jangg & T Doertbudak 'Platinum group metals – mercury and rhenium – mercury systems' **Z Metallk** 64, 10 (1973) 715–719. J Percy **Metallurgy: Silver and Gold** pt 1 London 1880. E A Smith as note 32.

TABLE 3

Experience over the last century and a half is ample evidence for the difficulties in removing PGE traces from gold with most usual refining methods. The chronology of refining in antiquity is still debated but by the beginning of our era a variety of techniques were known some of which had been in use for a considerable length of time. The effects of these refining methods are summarised in Table 3. It would seem that only amalgamation would have any significant effect on associated platinoids, it would tend to remove Os-Ir particles but would have little effect on Pt or Pd. An aureus of Nero of the Rome mint analysed by Cope shows a very high purity (about 99.5% Au) reflecting efficient refining but contains minute traces of numerous elements including Pd and Pt (but not Ir, Os, Ru nor Rh)[23]. Pd and, though perhaps to a lesser extent, Pt still occur in minute traces in modern gold alloys and even fine gold (in some fine gold Pd > Ag and Cu).

Refining techniques could be combined or elaborated and the Leiden Papyrus, Diodorus and Pliny[24] are among the sources for such recipes. In one test, gold with platinoid inclusions was fused with a mixture of salt and alum (comparing with some of the ancient recipes) and the visible result appeared to be a slight lessening of platinoid content but controlled experiments are required. When such a salt-based mixture was heated in contact with gold the surface platinoid inclusions in the gold were noticeably blackened and so it is possible that the blackish colour of the inclusions in a fine Egyptian gold ring[25] can be taken as tangible evidence for the various chemical pickling processes given in the ancient texts.

When gold containing platinoid inclusions is melted the inclusions, having high specific gravities, will usually settle to the bottom of the molten gold (this effect will be exaggerated by the presence of Ag and Cu alloyed with the gold) – the exceptions would be Ru rich particles with their lower s.g. or very small particles that could remain suspended in the gold. Such settling has been used in recent times as a separation technique. This means that the platinoid inclusions will not be uniformly distributed through a series of articles or ingots cast from one batch of molten gold, neither will they be unformly distributed within the individual items but, rather, will often be congregated at the lower part of the item. For example six gold solidii of Justinian I (part of a girdle found in Egypt) examined by the writer all showed more inclusions on one side that the other (the ratios for the inclusions visible at 20X magnification were 65:5. 2:0, 50:0, 22:1, 9:3, 50:9) this suggests that in casting the coin blanks or 'flans' were horizontal not vertical.

The presence of platinoid inclusions seems to have made little difference to the beating out of thin gold sheet or foil, in some cases an inclusion is thicker than the foil and is exposed on both sides. This must have been partially due to the softness of the tools and the usual practice of sandwiching the gold between layers of leather or 'gold-beaters' skin' although Riemsdyk did note in the last century that gold with platinoid inclusions will pass satisfactorily through steel rolling mills.[26] This same authority did say, however, that it was almost impossible to draw wires from gold with platinoid inclusions.

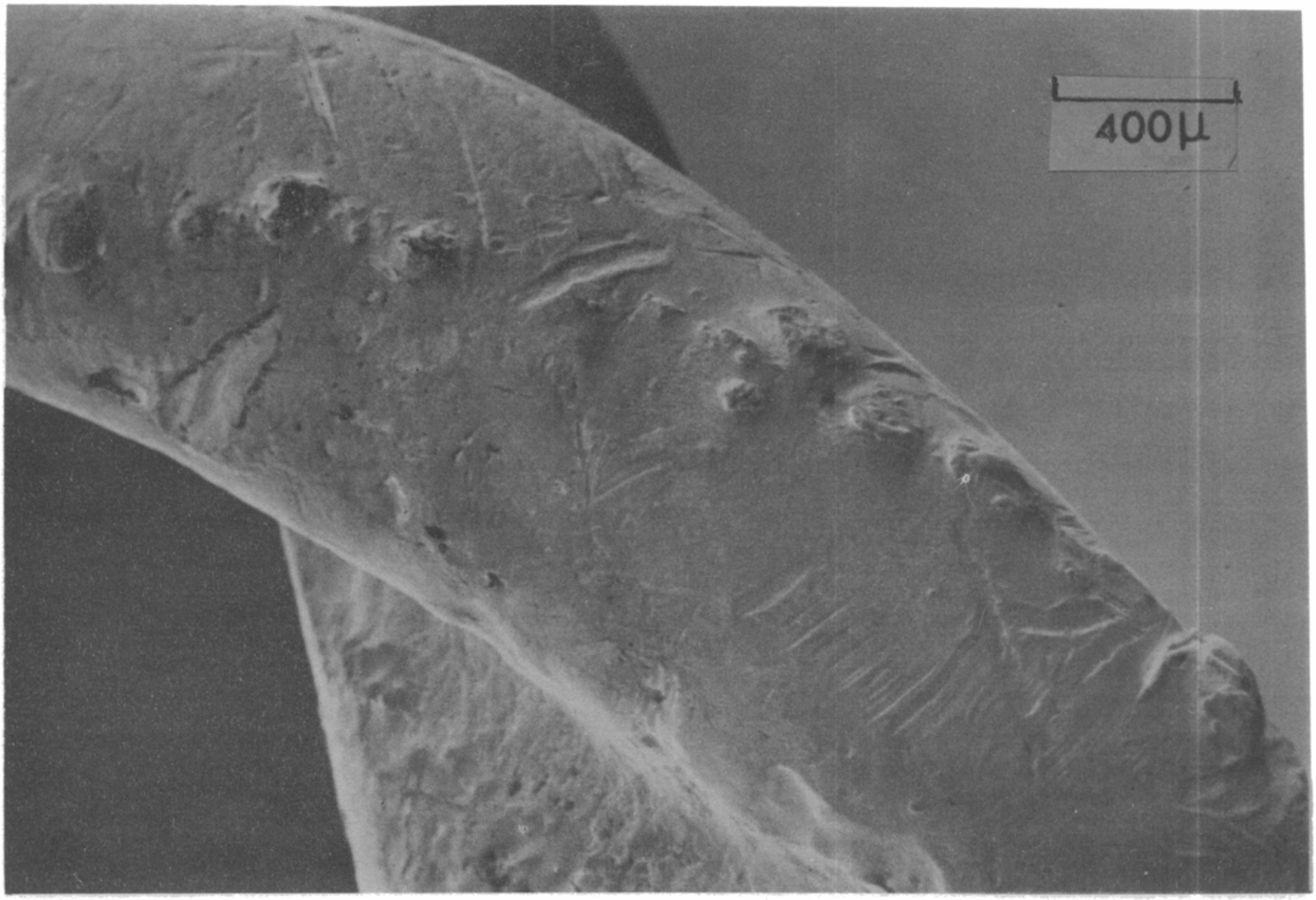


Figure 3 The longitudinal alignment of platinoid inclusions in the wire of a Roman gold earring (as Figure 6). The wire showed evidence for having been made by a strip twist technique, see text.

This could be one factor explaining the relatively late introduction of wire drawing as we know it today. Most ancient gold wires were probably produced by drawing a straight or twisted strip or ribbon of gold through a perforation in metal, bone or stone,[27] this did not involve the inherent alteration of the internal structure of the metal, and huge forces needed, in modern rod or wire drawing but the distinct longitudinal alignment of platinoid inclusions in some samples of ancient strip drawn wire indicate that considerable force was used on some occasions (Figure 3).

When gold is deformed by hammering, striking or swaging, any surface platinoid inclusions will literally be driven into the gold surface. This effect, visually different from the appearance of inclusions in cast items, will generally be masked by eventual polishing or wear but in some cases, as with the Byzantine coins mentioned above, is noticeable. Platinoid inclusions are obvious obstructions for an engraving tool and engraved lines in ancient goldwork can sometimes be seen to stop abruptly – a platinoid inclusion acting as an effective road-block. The inclusions can be extremely hard, a prominent inclusion will scratch rock crystal, and during the last century Wohler noted that they would blunt a steel file[28]. It is generally believed that fine metal files were not used by goldsmiths in antiquity and that a variety of stone abrasives (and similar substances such as charcoal, pottery etc) were used. The fine and relatively soft stone abrasives used on goldwork, along with eventual wear, usually had the effect of making the inclusions stand proud of the gold surface (Figure 4), an effect sometimes found to a remarkable degree. Recent polishing of ancient gold will of course have a similar result. In one case recently noted by the writer, a Roman ring (private collection), the interior of the shank had been repolished – perhaps after a repair – with a modern rotary polishing buff. This had resulted in all the numerous platinoid inclusions on the inner surface of the shank being given similarly orientated gold tails (a miniature version of the geologists' 'crag and tail' – a result of glacial erosion).

Judging by the experience of native gold washers in many parts of the world in historic times and the plaintive comments of goldsmiths over the last century or so it seems hardly plausible that early people could have remained in total ignorance of the platinum group of metals. Some platinoid inclusions in gold items are visible to the naked eye (sometimes even through the glass of a museum case) and could have been noted by the artisan if not by his patron whilst the larger platinoid nuggests, often Pt or Pt – Fe could have been seen and picked from the associated gold – one such grain certainly formed the small inlay in a Late Period Egyptian box[29]. Its use in this case showed that it had been mistaken for silver rich electrum, in other cases a confusion with iron might have been possible.

Literary references to platinum metals in antiquity have not been proved; De Rubies believed that Pliny's 'white lead' found with some Spanish gold was really our platinum[30] but the well known occurrence of tin – the usual translation of 'white lead' – in Spanish gold mines makes this highly

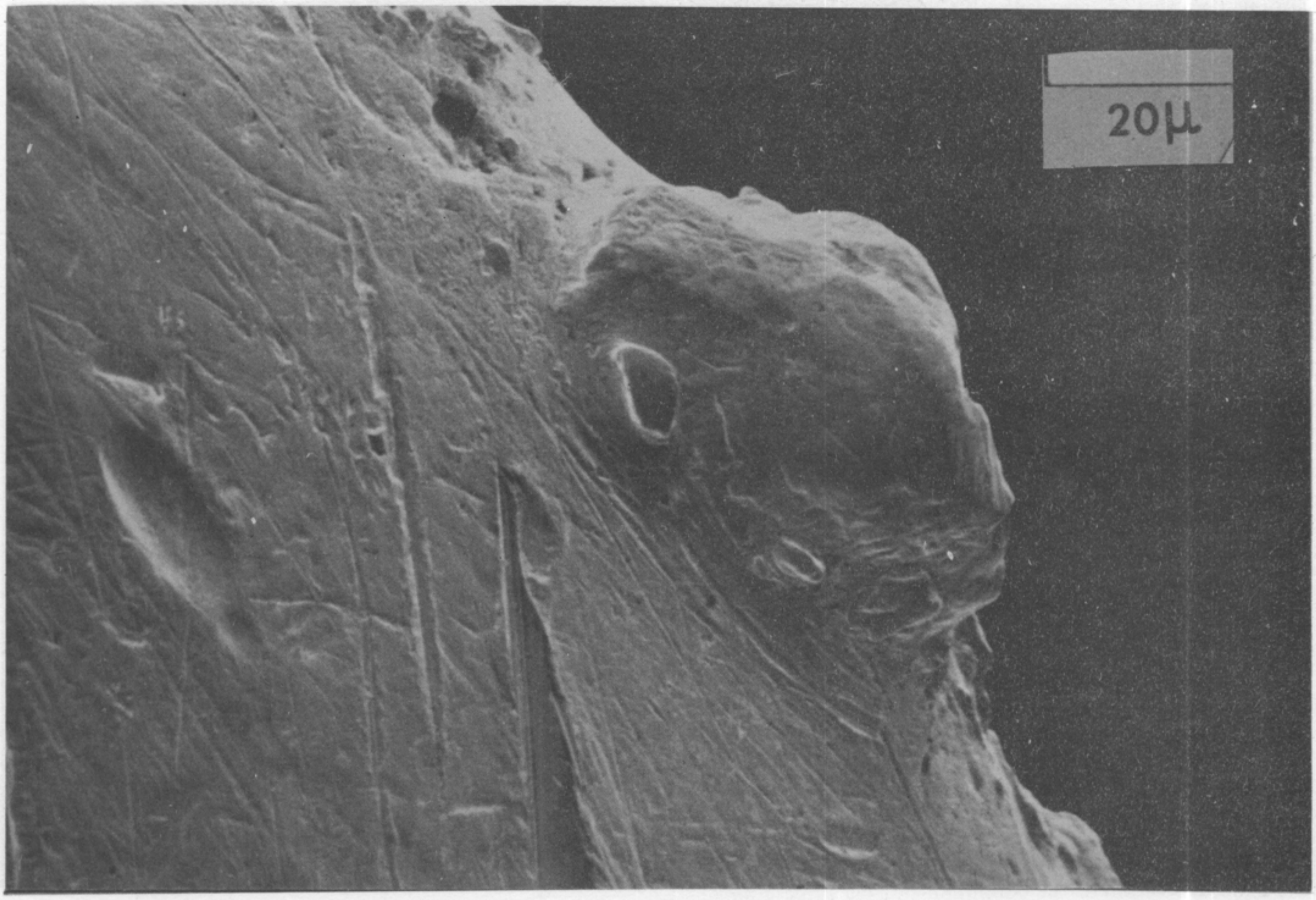


Figure 4 Detail of an inclusion from the same wire as Figure 3. Qualitative XRF analysis showed Ir >Os, hence osmiridium.

unlikely despite the known association of PGE with gold in numerous Spanish gold placers. A mention of platinum metals by Pliny, however, is quite possible. He describes at some length a series of minerals all covered by the name **'adamas'** which literally means invincible.[31] By Pliny's time diamond was included here – he describes its transparency, crystal form and Indian source – as well as an Arabian type (possibly diamond traded from India via the Red Sea) and a couple of forms that he admits were not really worthy of the name but he devotes most space to what he clearly indicates was the original bearer of the name. He follows earlier writers in calling this the 'knot of gold' as it was 'found very occasionally in mines in association with gold and, so it seemed, formed only in gold'. This 'knot of gold' had a 'silvery pallor' and compared in size to millet or cucumber seeds. There were two varieties, that from gold mines in Nubia and/or Sudan and that from the gold mines of Macedonia. This description certainly brings to mind our platinum metal grains but does not apply to diamond although there are a few world-wide occurrences of diamonds in goldmines. The other properties of the original **adamas** also compare to those of platinoids. They 'conquer fire', cannot be flattened with a hammer (both hammer and anvil supposedly break in the attempt) and supposedly 'seized' iron more readily than a magnet. Platinum metal grains indeed would have conquered any ancient fire, the individual PGE have very high melting temperatures that would have been unobtainable in antiquity (some Os – Ir grains have melting temperatures over double that obtained in iron production furnaces). On the other hand diamond can be affected even in quite simple hearths. The mechanical deformation of Os – Ir grains is almost impossible even today, diamond, however, though very hard, is brittle and can easily be shattered by a hammer blow – as many a prospector has found to his horror. The magnetic properties are those usually taken to be the most nonsensical of all Pliny's descriptions of adamas but in fact, whilst diamond has no magnetic properties, Pliny's description almost mirrors that of Smith who reported that some Uralian specimens of platinoid grains were said 'to attract iron filings more powerfully than an ordinary magnet'.[32]

This resemblance between Pliny's **'adamas'** and platinoid grains might be purely fortuitous but a similarity is obvious. Pliny appears to have based much of his knowledge of **adamas** on Egyptian authorities and it must be noted that Egypt is the only country where there is a certain ancient use of platinum group metals for decorative purposes – albeit probably unintentionally. The name adamas itself has been compared with the Akkadian 'algamisu', a very hard substance, which in turn has been connected with the Egyptian 'Irkbs' – a mineral included in a list of tribute from Nubia[33]. Earlier Classical writers use **adamas** in the context of either great wealth and value or else immense hardness and strength. It is possible to believe that other hard substances, including perhaps iron or steel, were sometimes meant but platinoid grains are far harder than steel and, from their other properties and mode of occurrence, rarer and more noble than even gold.

Possible sources of gold with associated PGE

The presence of platinoid grains in placer deposits with gold and as inclusions in ancient gold artifacts is extremely common, perhaps some PGE association with gold in placers throughout the world is the rule rather than the exception. The underestimation of the commoness of platinoid grains in gold placers can lead, and has led, to over-hasty conclusions regarding possible sources and trading contacts. Information on the occurrence of PGE outside of major production centres such as the USSR, South Africa, Canada, Borneo etc is limited but on the evidence that has been available to the present writer it would seem that platinoid grains would have been found in association with gold from most of the placer gold deposits exploited in antiquity. The map indicates the more important gold sources in antiquity, details of any known PGE association are given below.[34]

1. **Ireland** The finding of small traces of Pt in Iron Age gold items from Ireland has resulted in a debate regarding the source of the gold and thus the possible presence of PGE in Ireland. In view of the conflicting reports the following 'first hand' report is quoted in full, it refers to a Wicklow stream. 'Mixed with the gold are some very small flattened grains of a white colour and metallic lustre, which, as far as their minute size permitted me to examine them, appear to present all the characteristics of platina. They are infusible before the blowpipe, and insoluble in nitric acid, but dissolve in aqua regia. Their occurrence intermixed with the gold when all other minerals have been washed off, is a proof of their high specific gravity.'[35] From their solubility in aqua regia but not nitric acid the grains would be predominantly Pt or Pt – Fe, not Os – Ir, and thus this Wicklow gold would be a suitable source for the goldwork mentioned above. The apparent correlation of Pt with Ni in goldwork in the Broighter hoard from Ireland is matched, however, in late Iron Age jewellery and coinage from the Rhine valley and South Germany.[36] Platinoid inclusions have recently been noted in Irish goldwork of 6th century AD.[37]

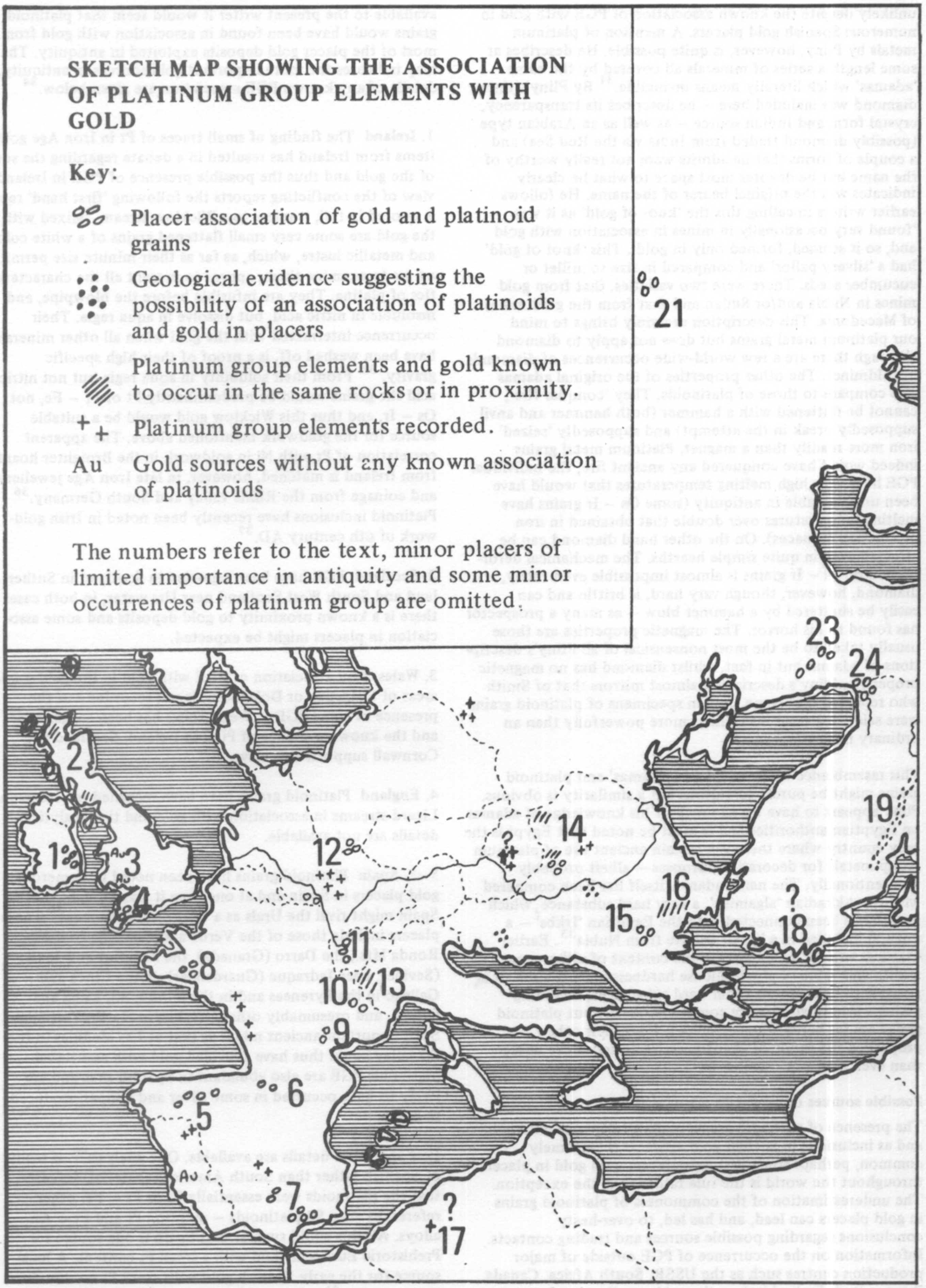
2. **Scotland** PGE have been reported in Scotland in Sutherland and South West Scotland near Urr water, in both cases there is a known proximity to gold deposits and some association in placers might be expected.

3. **Wales** Any association of PGE with gold in the gold mining areas of Dolgellau or Dolaucothi is not recorded but the presence of some PGE in Welsh rocks has been suggested[38] and the known presence of PGE in Ireland, Scotland and Cornwall supports this view.

4. **England** Platinoid grains have been recorded in placers in Lizard streams in association with gold and tin; analytical details are not available.

5–7. **Spain** Platinoid grains have been noted in numerous gold placers in Spain and at one time it was thought that Spain might rival the Urals as a platinum producer.[39] These placers include those of the Verde and Guadaija in the Ronda Mts., the Darro (Granada), the Penaflor and Jenil (Seville), near Jadraque (Guardalajar), in the Cinca and Gallego in the Pyrenees and in the Minho, Sil, Luna and Orbiga, and presumably other streams, in North West Spain. Such important ancient mines as that at Las Medulas in the Sil valley could thus have provided gold with associated platinoids.PGE are also abundant in Spanish ores and are likely to have occurred in some silver and copper produced in Spain.

Few analytical details are available. One analysis[40], if really of Spanish rather than South American material, suggests that the platinoids were essentially Pt or Pt – Fe; other references – to Sil platinoids – mention Pt and Pt – Au alloys. All this could suggest that Spain is one source for Prehistoric European gold with a small Pt content. A local source for the early Spanish gold with small Pt content is also probable.[41] There is less evidence for PGE in Portugal

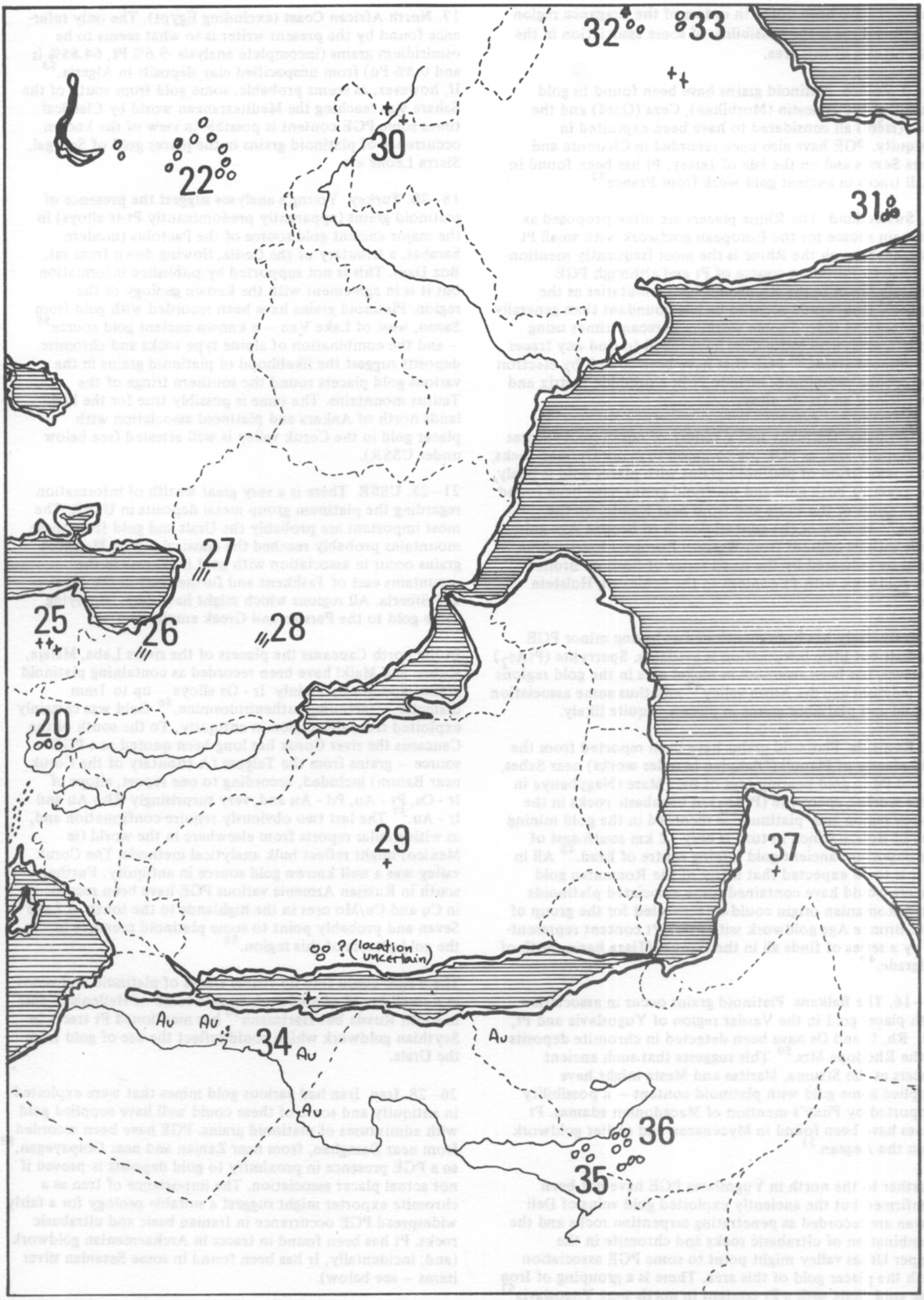


SKETCH MAP SHOWING THE ASSOCIATION OF PLATINUM GROUP ELEMENTS WITH GOLD

Key:

- ∘∘ Placer association of gold and platinoid grains
- ⁘ Geological evidence suggesting the possibility of an association of platinoids and gold in placers
- ▨ Platinum group elements and gold known to occur in the same rocks or in proximity.
- + + Platinum group elements recorded.
- Au Gold sources without any known association of platinoids

The numbers refer to the text, minor placers of limited importance in antiquity and some minor occurrences of platinum group are omitted.


32
33
30
22
31
27
25
26
28
20
29
37
location uncertain
Au
Au
Au
34
Au
Au
36
35

but they have been noted in orders of the Braganca region and thus there is the possibility of some association in the gold placers of this area.

8–10. **France** Platinoid grains have been found in gold placers of the Penestin (Morbihan), Ceza (Gard) and the Drac (Isère) all considered to have been exploited in antiquity. PGE have also been recorded in Charente and Deuz Sevres and on the Isle of Jersey. Pt has been found in small traces in ancient gold work from France[42]

11. **Switzerland** The Rhine placers are often proposed as the main source for the European goldwork with small Pt content. Though the Rhine is the most frequently mentioned Western European source of Pt and although PGE certainly occur in the Rhine and such tributaries as the Wigger[43] they would seem to be less abundant than generally supposed and indeed some workers in recent times using modern analytical techniques have failed to find any traces of platinoid grains.[44] PGE that have been found, by electron microprobe techniques, include Pt in a sulphide matrix and a particle of an Os–Ir alloy.

12. **Germany** Germany had a variety of minor gold sources in antiquity and, as PGE are common in many German rocks, some association of platinoid grains with placer gold is likely. For example both gold and platinoid grains have been found in the sands of the Saale and from near Kandel on the Rhine.[45] In view of the general dearth of Bronze Age goldwork with Pt content from Western Europe a local source might be indicated by the small series of finds of Bronze Age goldwork with Pt content in the Schleswig Holstein area.[46]

13. **Italy** Italy has been mentioned as having minor PGE deposits but little information is available. Sperrylite ($PtAs_2$) however, has been recorded in nickel ores in the gold regions of Piedmont and the Aosta valley[47] and thus some association of gold and platinoid grains in placers is quite likely.

14. **Romania** Platinoid grains have been reported from the gold placers of Pianuli (Olahpian in older works) near Sebes, Pt and Pd in gold bearing ores of Baia Mare (Nagybanya in older works), sperrylite ($PtAs_2$) in ultrabasic rocks in the Brasov region and 'platinum' is recorded in the gold mining area of Boicza which in turn is only 12 km south east of the important ancient gold mining centre of Brad.[48] All in all it is to be expected that many of the Romanian gold placers would have contained some associated platinoids and a Romanian origin could be suspected for the group of Late Bronze Age goldwork with small Pt content represented by a series of finds all in the Danube/Tisza basin north of Belgrade.[49]

15–16. **The Balkans** Platinoid grains occur in association with placer gold in the Vardar region of Yugoslavia and Pt, Pd, Rh, Ir and Os have been detected in chromite deposits in the Rhodope Mts.[50] This suggests that such ancient placers as the Struma, Maritsa and Mesta might have supplied some gold with platinoid content – a possibility supported by Pliny's mention of Macedonian **adamas**. Pt traces have been found in Mycenaean and earlier goldwork from the Aegean.[51]

Further to the north in Yugoslavia PGE have not been confirmed but the anciently exploited gold veins of Deli Jovan are recorded as penetrating serpentine rocks and the combination of ultrabasic rocks and chromite in the Upper Urbas valley might point to some PGE association with the placer gold of this area. There is a grouping of Iron Age gold finds with a Pt content in north west Yugoslavia[52]

17. **North African Coast** (excluding Egypt). The only reference found by the present writer is to what seems to be osmiridium grains (incomplete analysis -9.6% Pt, 64.85% Ir and 0.8% Pd) from unspecified clay deposits in Algeria.[53] If, however, as seems probable, some gold from south of the Sahara was reaching the Mediterranean world by Classical times some PGE content is possible in view of the known occurrence of platinoid grains in the placer gold of Senegal, Sierra Leone etc.

18–20. **Turkey** Young's analyses suggest the presence of platinoid grains (apparently predominantly Pt-Ir alloys) in the major ancient gold source of the Pactolus (modern Sarabat, a tributary of the Gediz, flowing down from mt. Boz Dag). This is not supported by published information but it is in agreement with the known geology of the region. Platinoid grains have been recorded with gold from Sason, west of Lake Van – a known ancient gold source[55] – and the combination of alpine type rocks and chromite deposits suggest the likelihood of platinoid grains in the various gold placers round the southern fringe of the Taurus mountains. The same is possibly true for the highlands north of Ankara and platinoid association with placer gold in the Coruk valley is well attested (see below under USSR).

21–25. **USSR** There is a very great wealth of information regarding the platinum group metal deposits in USSR. The most important are probably the Urals and gold from these mountains probably reached the classical world. Platinoid grains occur in association with gold in placers in the mountains east of Tashkent and further east in the Altai and Siberia. All regions which might have been supplying some gold to the Persian and Greek empires.

In the north Caucasus the placers of the rivers Laba, Malaja, Kuban and Malki have been recorded as containing platinoid grains, apparently mainly Ir - Os alloys – up to 1mm diameter – including rutheniridosmine.[56] Gold was certainly exploited from this region in antiquity. To the south of the Caucasus the river Coruk has long been quoted as a PGE source – grains from the Talgom (A tributary of the Coruk near Batum) included, according to one report, alloys of Ir - Os, Pt - Au, Pd - Au and, very surprisingly Rh - Au and Ir - Au.[57] The last two obviously require confirmation and, as with similar reports from elsewhere in the world (ie Mexico) might reflect bulk analytical methods. The Coruk valley was a well known gold source in antiquity. Further south in Russian Armenia various PGE have been recorded in Cu and Cu/Mo ores in the highlands to the south of Lake Sevan and probably point to some platinoid presence in the gold placers of this region.[58]

The writer could find no visible traces of platinoid inclusions in a small hoard of goldwork from a tomb of Hellenistic date in south Russia but Hartmann[14] has mentioned Pt traces in Scythian goldwork which could reflect the use of gold from the Urals.

26–28. **Iran** Iran had various gold mines that were exploited in antiquity and some of these could well have supplied gold with admixtures of platinoid grains. PGE have been recorded from near Damghan, from near Zanjan and near Golpayegan,[59] so a PGE presence in proximity to gold deposits is proved if not actual placer association. The importance of Iran as a chromite exporter might suggest a suitable geology for a fairly widespread PGE occurrence in Iranian basic and ultrabasic rocks. Pt has been found in traces in Archaemenian goldwork (and, incidentally, Ir has been found in some Sasanian silver items – see below).

29. **Arabia** Strabo and other ancient writers support the view that Arabia was an important gold source to Western Asia in antiquity. Most of the gold mines are situated in the western highlands where placer Os - Ir alloy grains have been found and auriferous quartz veins occur cutting serpentinites.[60] A possible platinum source has recently been located south west of Shaqra – in the vicinity of known ancient silver mines.[61] A hoard of south Arabian goldwork (probably late 1st millennium BC) studied by the writer (about 200 individual pieces) showed no signs of platinoid inclusions but did contain a remarkably high lead content – about 3-4% probably reflecting extractive or refining methods. Axumite gold coins from south Arabia have been found to have a small Pt content but an origin in Ethiopa is likely.

30–33. **India and Pakistan** There are frequent references to platinoid grain association with gold in many placer deposits in India[62] including the Noa river (Assam), the Guram (Dhadka) and gold washings of the Kolar mine (Mysore) and 'near Bonai city' (supposedly Pt + Ir particles). Other unspecified occurrences are in Khangawan, Darwar, Singhbhum and Midnapur and also in the ultrabasic rocks of Kashmir. Reports regarding Pakistan are in disagreement and some official surveys make no mention of any presence. The frequently quoted report of platinum being found in the Indus seems to be partially due to a misunderstanding in the writings of Baden Powell but the presence of some platinoid grains in gold placers of the Kohat region, as has been reported, is quite likely. This is supported by the known geology of this region; the geology is also suitable in the Zhob valley and this, together with the known presence of platinoid alloy grains in gold placers in Tadzhikistan could indicate some PGE occurrence, otherwise unrecorded, in Afghanistan. The classical writers give ample proof that India was an important source of gold to the Persian, Hellenistic and Roman empires.

34. **Egypt** Despite the extreme commoness of platinoid inclusions in Egyptian goldwork[63] there have so far been no reports of any platinoid association with gold in Egyptian mines. In many areas the geology is suitable; there are ultrabasic rocks in association with chromite and in some gold mining areas – as at El Sid in the Wadi Hammamet and at Baramia – auriferous quartz veins actually cut serpentine rocks. The only confirmed PGE source within Egypt is a small Pt trace, about 1 ppm, in the nickel ores on the Isle of St John (Zebirget).[64]

If platinoid inclusions were found in a representative selection of Egyptian goldwork dating from the 1st Intermediate Period or earlier this would be an almost certain indication that the Eastern Desert gold placers contain some platinoids. The sheer profusion of ancient Egyptian gold with platinoid inclusions from later periods clearly shows the presence of platinoid grains in goldfields directly exploited by the Egyptians, that is north of about the 18th parallel.

35–36. **Ethiopia and the Sudan** There are no official references to platinum occurring with gold in the Sudan but in the last century Cailliaud mentioned 'platiniferous gold' in the Sudan near the Ethiopian boarder[65] and the above mentioned reference by Pliny to **'adamas'** occurring with gold between Philae and Meroe could possibly mean a platinoid association in this region. In Ethiopia platinoid grains are well attested, occurring with gold in the Beni Shangul area and in the gold placers of the Birbir and Didessa valleys.[66] Pt itself is most abundant, although grains of Os - Ir alloys also occur, and a local source for Axumite gold coinage with a small Pt trace is likely. Platinoid grains have not been reported in Eritrean placers.

37. **Somaliland** The land of Punt – a source of gold to the Egyptians – is often supposed to lie in Somaliland. A source of PGE has been found in Somaliland (north east of Haduya)[67] but an association with gold in placers has not been confirmed. Further south gold from Madagascar, Rhodesia etc is known to have associated platinoids and some gold from such regions could have been reaching the Ethiopian or Mediterranean kingdoms by the later periods of antiquity.

Non-placer origins for PGE traces in gold

It is normally assumed that PGE traces in ancient gold artifacts reflect placer origins for the gold. This is perhaps not invariably true. There are a handful of reef gold occurrences around the world where a PGE association with the gold has been found and though these might, as far as the geologist is concerned, usually represent some form of secondary deposition it still means that the ancients could have obtained some gold with associated PGE from other than normal alluvial workings. In some of these secondary deposits the PGE appear to be in chemical combination with the gold; for example, traces of Pt and Pd appear in gold from a contact metamorphic deposit in British Columbia.[68] There are also cases where minute traces of Pt and Pd have been found in placer gold nuggets – perhaps being carried by the minute sulphide inclusions present[69] – and of cases where auriferous quartz veins traverse platiniferous rocks – as at Yubdo, Ethiopia.[70]

Another possibility is the unintentional adding of PGE to gold in post-retrieval processes, during refining by the sulphide process – sulphides are frequent carriers of PGE, or as a result of alloying with Ag or Cu. Many Ag and Cu ores contain PGE and traces of these metals are known in both ancient and recent silver and copper items. PGE, including Os - Ir particles were recorded in silver coinage in the last century and Ir has been detected in British silver of the Georgian period. With ancient items of silver PGE traces seem to be detected whenever sensitive analytical methods are used, for example Ir in Sasanian silver[71] and Ir and Pd in early Scottish silver[72]. Similarly PGE have been found in anicent copper alloy articles – such as Pt in a Bronze Age halberd blade from Co. Mayo, Ireland[73] although an Irish source for the ore is not necessarily indicated.

The analysis of the inclusions

It is usually possible to distinguish between the hexagonal and cubic phases of Os - Ir grains in polished section on the basis of colour, reflectivity and polishing hardness without recourse to other or microscopic techniques but so far the differentiation between iridosmine and rutheniridosmine is not possible by such means. Accurate quantitative analysis relies on the use of the electron microprobe – the Lα lines are used for the platinum metals and the Kα lines for Cu, Ni, and Fe and there is a published computer programme for corrections[74]. Even so prior microscopic examination of polished grains is advisable where possible to determine the extent of zoning and intergrowths. The existence of two or more phases or compositional zoning is found in many platinoid grains from worldwide deposits[75] and a combination of hexagonal and cubic phases have been found in single inclusions in ancient gold. (Figure 5) A series of point analyses is useful when more than one phase or composition zoning is suspected but can be difficult with the varied topography of unpolished inclusions in situ in a gold object. In some cases it is possible to remove an inclusion to facilitate examination – it can be mounted and polished – in general the inclusions can be removed with very little damage to the gold. In some cases they can be dislodged with the slight

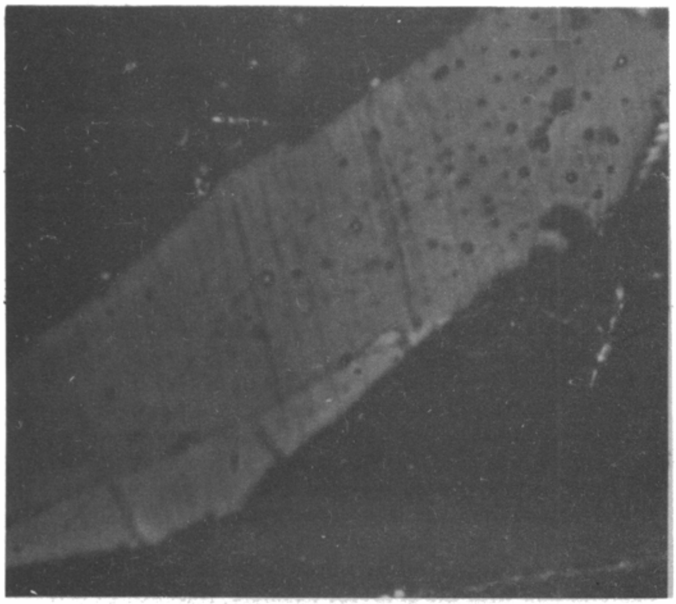


Figure 5 Polished section of gold with an inclusion comprising two phases (= Fig 7 inclusion No.9), the specimen had been vacuum carbon coated to increase phase contrast and the darker phase is in fact cubic (Ir >Os >Pt) the paler phase hexagonal (Os > Ir), uncoated and under usual lighting the cubic phase would appear the paler. Width of inclusion about 15 μm.

pressure of a thumb nail, in other cases a microscalpel proves suitable.

Of course, not all the inclusions in ancient gold are of the platinum metals. Silver chloride, carbonaceous matter and other substances have all been found and in several cases silvery specks on the surface of ancient gold items have proved to be minute flecks of silver foil – perhaps 'pick-up' from the tools used in the mechanical forming of the gold. Small spatters of soft solder (lead/tin) and silvery patches due to contact with mercury have also been noted on ancient gold but usually reflect the very recent history of the items, repairs or accidental contacts.

For financial reasons an analytical programme has not been part of this study (work on these lines is in progress elsewhere) but a few analyses by X-ray fluorescence and electron microprobe have been carried out with the help of various laboratories and are detailed briefly below. The results are only to be taken as indications of composition, and in most cases only one spot analysis was made on each inclusion.

Figure 6 Pair of Roman gold earrings from Anatolia, actual size, private collection.

Item A A pair of Roman gold earrings **(Figure 6)** c. 2nd century AD from Asia Minor. These earrings contain a very large number of inclusions (many hundreds) and were examined to gauge the extent of variation in the composition of inclusions within a single item. Preliminary qualitative analysis of one inclusion in situ showed it to be mainly Os + Ir with only minor traces of Rh and Ru. Minute fragments of wire were carefully removed from one of the earrings, mounted and polished. One fragment contained a group of 9 inclusions (Figures 7, 8 5) and microscopic examination indicated the presence of both hexagonal and cubic phases, one inclusion consisting of both phases with a distinct interphase boundary (Figure 5). Simultaneous analysis for Os and Ir showed the nine inclusions to have a range of compositions (Table 4) but bearing in mind the possibility of varied Pt and Ru contents all approximated to either 60% Os + 40% Ir or 40% Os + 60% Ir. (Later XRF analysis confirmed the presence of two phases in inclusion No. 9). In another mounted wire fragment from the same earring three closely grouped inclusions were analysed by electron microprobe for Os, Ir and Ru (Table 5, nos. 1–3), their compositions matched the indications based on their colours, 1 and 3, respectively rutheniridosmine and iridosmine, were bluish-grey, 2 was creamy white and must approach being native iridium (ie Ir >80at%) but this is uncertain due to the unknown value for the Pt.

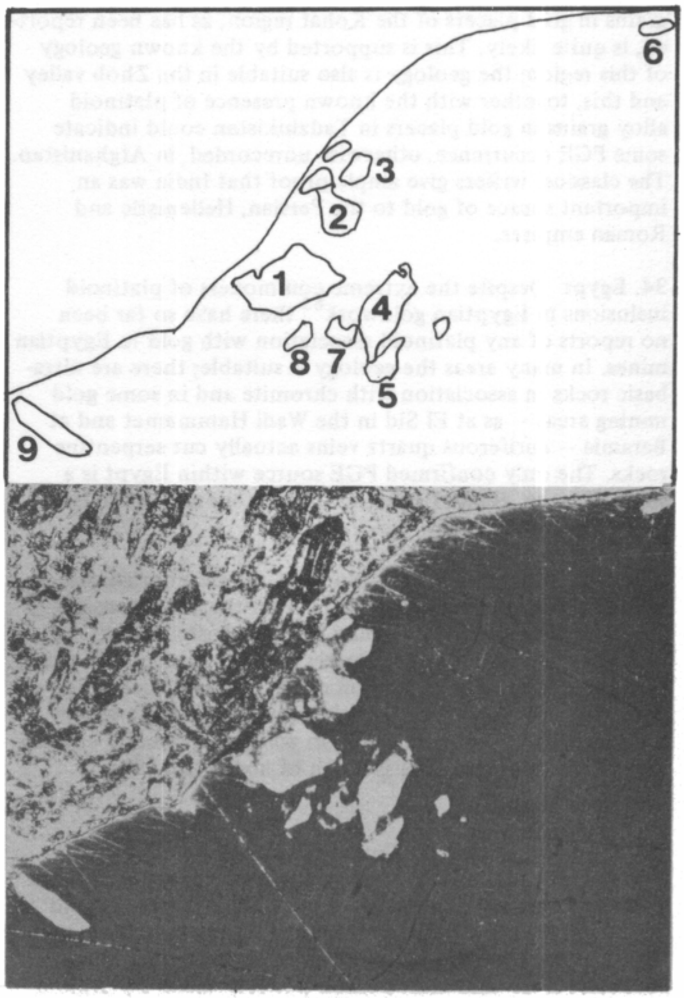


Figure 7 **Polished section of gold wire from Roman earring (Fig 6), Platinoid inclusions show white against dark gold (Bakelite mount shows some roughness due to SEM examination), compare figure 8 for scale. Numbers refer to Table 4.**

Item B A Dark Age gold and garnet brooch, western European and supposedly found in France. One surface inclusion was carefully removed and analysed for Os, Ir, Ru and Pt (Table 5 nos. 4 and 5). The two analyses, of different areas of the same inclusion, suggest that the inclusion was fairly homogeneous and clearly rutheniridosmine. The high Ru value is worth noting.[76] The gold of the brooch was about 98 wt% Au.

Item C This was an interesting Egyptian gold ring of the time of Akhenaton c. 1400 BC (Figure 9). The gold was of the reddish colour much favoured at that period; so far only a qualitative analysis has been carried out on the gold which showed Au: Cu: Ag to be about 2:2:1. One platinoid inclusion was analysed (Table 5, no. 6) and proved to be rutheniridosmine. A previous analysis of an inclusion in a later Egyptian gold ring[77] showed the presence of osmiridium whilst inclusions in an 18th Dynasty gold button[78] were apparently iridosmine or rutheniridosmine.

Item D A Scythian style gold plaque in the form of a seated, winged sphinx (Figure 10). This is of interest as the piece is a fake (microscopic examination showed the use of rolled sheet, steel dies, cutting out with scissors and the use of drawn wire for the suspension loops). The inclusion removed and analysed was iridosmine (Table 5, no. 7 and Figure 11), the gold was 78 wt% Au, 11 wt% Ag and 11 wt% Cu and could well be a commercial 18 carat alloy (75 wt% Au).

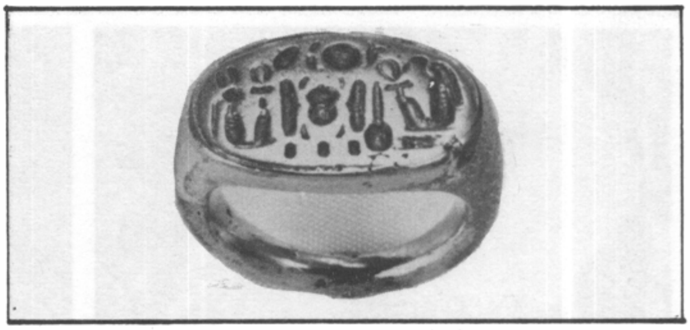


Figure 9 An Egyptian gold ring of the time of Akhenaton, c 1400 BC. The characteristics of the inscription date it to the early part of his reign. Now in a private collection the ring has been published in Newberry Scarabs Pl xxxi, 21. The Inclusion analysed was on the side of the ring just below the lower right of the bezel. X 2.

Figure 10 Fake Scythian gold plaque in the form of a lying, winged sphinx. The inclusion analysed was on the front edge of the hind leg. Actual size (one piece from a large collection of such items).

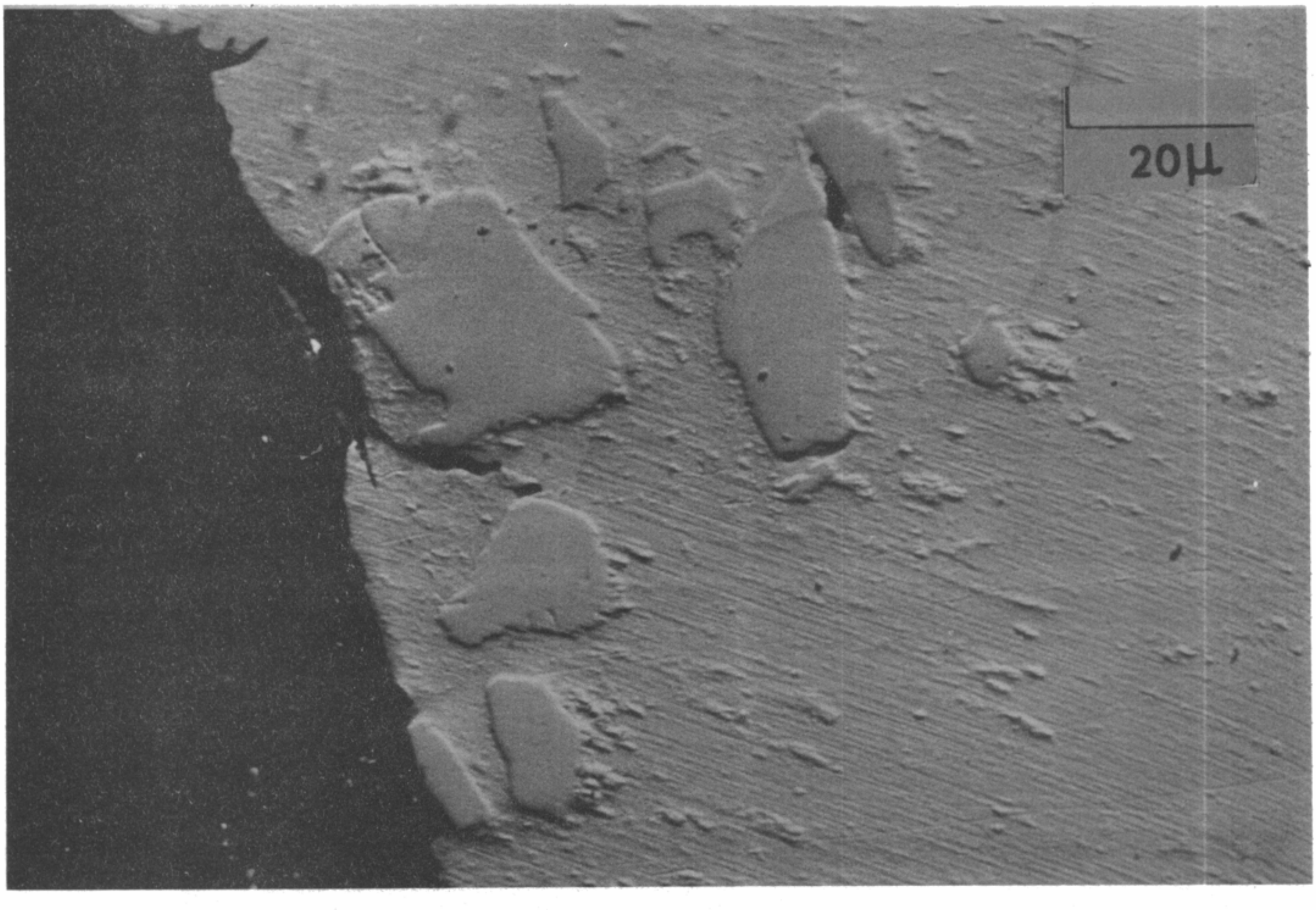
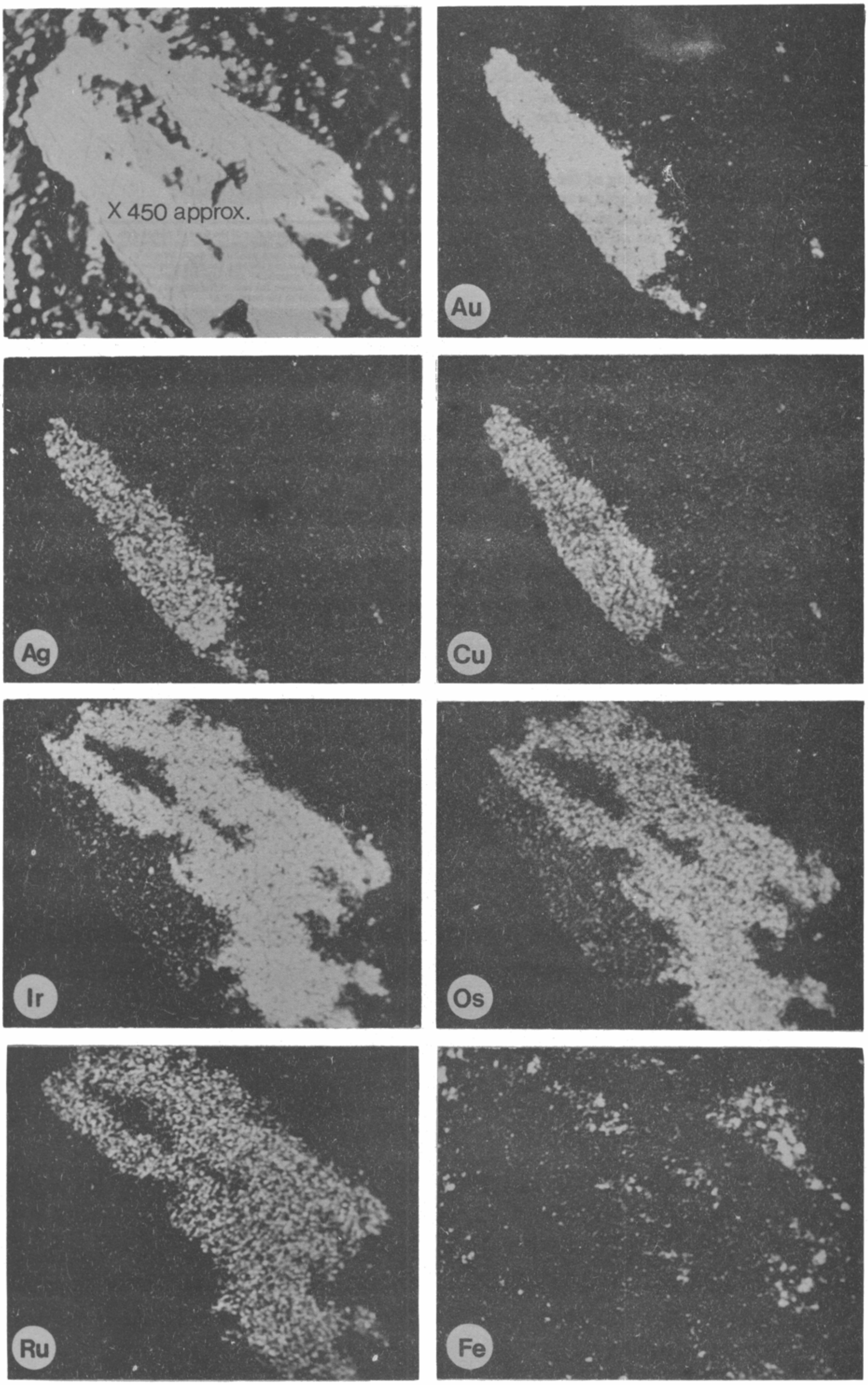


Figure 8 Detail of central group of inclusion of Figure 7. The relief due to the hardness of the inclusions compared to the gold is clearly seen.



THE COMPOSITION OF A PLATINOID INCLUSION FROM A FAKE SCYTHIAN GOLD PLAQUE (See Table 5, analysis 7)

The gold rich area to the lower left is gold from the body of the item adhering when the inclusion was removed and mounted. The apparent partial diffusion of some Ir and Os into this area needs confirmation.

Figure 11

Inclusion No.	Ratio of Os:Ir Os	(Total 100) Ir	Colour	Phase
1	37	63	creamy grey	cubic
2	33	67	creamy grey	cubic
3	60	40	bluish grey	hexagonal
4	43	57	creamy grey	cubic
5	62	38	bluish grey	hexagonal
6	55	45	bluish grey	hexagonal
7	43	57	creamy grey	cubic
8	54	46	bluish grey	hexagonal
9*	41	59	creamy grey	cubic

THE VARIATION OF Os:Ir IN A GROUP OF INCLUSIONS IN A ROMAN EARRING

The analyses are numbered as per Figure 7. The colour is as seen in polished section with reflected light and oil immersion, the crystal phase is as deduced from the Os:Ir ratio, the colour and polishing hardness.

*Inclusion 9 consisted of both hexagonal and cubic phases (Figure 5), the cubic phase was the one analysed.

TABLE 4

Analysis No.	Os	Ir	Ru	Pt	Nature	Item
1	29.2	21.0	49.8	nd	rutheniridosmine	Roman earring
2	12.4	81.2	6.4	nd	?osmiridium	ditto
3	58.4	37.2	4.4	nd	iridosmine	ditto
4	25.4	12.5	57.9	4.0	rutheniridosmine	Dark Age brooch
5	25.4	13.4	56.5	4.0	rutheniridosmine	ditto
6	33.0	31.4	33.1	1.2	rutheniridosmine	Egyptian ring
7	56.4	40.1	2.5	nd	iridosmine	Fake Scythian item

SOME ANALYSES OF INCLUSIONS

1–3 polished section of gold 4–7 inclusions removed from gold by means of a scalpel.
nd = not determined, Rh and Pd not looked for.

TABLE 5

Source correlation

From the map it can be seen that of the important placer gold sources in antiquity only those in Wales and Egypt's Eastern Desert are without recorded PGE associations and even in these two cases some PGE presence has been suggested and, in the case of Egypt, could be considered likely. Considering the lack of published details regarding the nature of the platinoids found in most deposits and the variety of platinoids that can occur in a single item of gold, any correlation of gold item with gold source on the basis of the platinoid inclusions alone appears an unrealisable dream. Study of published analyses of placer platinoid materials from worldwide occurrences does indicate, however, that some patterns might emerge when there is a large enough corpus of analyses of inclusions in ancient goldwork.

Placer platinoid grains can usually be considered to represent two groups, those with predominantly Pt and those predominantly Os + Ir, although both types of alloy can occur within a single placer there is usually a predominance of one or the other. Using bulk analyses of total platinoids extruded from a placer it has been found that if the formula $\frac{Pt \times 100}{Pt + Ir + Os}$ is applied to individual placer deposits the resultant values appear to fall into two distinct groups >86 and <36 which reflect the geology of the source rocks. The higher values apparently correlate with what are called Alaskan type concentrically zoned intrusions, the lower values Alpine type intrusions.[79] On this basis gold items with Pt in solution should mainly come from the former type of deposit, gold items with numrous Os + Ir inclusions the second type. Deposits of the former type include the Birbir in Ethiopia and the Urals, the latter type include alpine complexes in the Tethyan zone – the mountain chains from Greece to west Pakistan. A great deal more work obviously needs to be done, however, for example the Ronda area of Spain and the Lizard in Cornwall have examples of a sub-type of alpine complex but are believed to be mainly Pt producers.

Some patterns might be derived from the relative abundances of the individual platinum metals (and perhaps Cu, Fe, Au etc) present in platinoid inclusions. One indication could be the extent to which Ru replaces Os in the hexagonal alloys. Material from Borneo, for example, on average plots nearer to the Os - Ir binary than material from New Guinea or Colombia[80]. Similarly New Guinea hexagonal platinoid grains seem to have a relatively high Pd, Rh and Cu content. All values being computed on atomic proportions. Similar patterns might eventually emerge from a study of the inclusions in ancient gold. If the presence of Pt - Ir alloy inclusions in some gold work from Asia Minor is confirmed[81] this could be an important source characteristic.

Other indications of source might be derived from the shape of the inclusions (ie the degree of rounding), the extent to which the inclusions are multi-phased or have compositional variations, or perhaps just the sheer abundance of inclusions. This last effect can be largely dependent on post-retrieval factors but a few generalised observations might be possible, for example in the writer's experience Egyptian jewellery usually has sparsely distributed inclusions whereas the items with a rash-like profusion of inclusions frequently originate in Asia Minor.

The lack of any PGE traces (in solution or as inclusions) in a representative selection of gold items from a particular period or region could reflect:

a. the exploitation of non-placer gold
b. primitive hand sorting of gold from a placer
c. efficient refining techniques
d. the exploitation of placers without PGE association

Of these the last is quite probably the least common.

Although source determination on the basis of even the most accurate analyses is still a long way off, a very great deal can be deduced from the appearance, orientation and arrangement of inclusions within an item of goldwork regarding goldworking methods and for the time being the value of inclusions to the archaeologist might well lie here. Any possibility of source correlation would need a very great increase in our knowledge of the geological distribution of platinoids and details of minor deposits. In the meantime any trade contacts based on PGE traces in goldwork should be treated with extreme caution. The very presence of platinoid inclusions in a very large proportion of ancient gold artifacts does show, however, the great extent to which the ancients obtained their gold from placer deposits and, from the minute size of some of the inclusions, illustrates the efficiency of the gold recovery methods.

ACKNOWLEDGEMENTS

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Continued from page 82 ROMANO–BRITISH IRON/AIANO

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Portskewett Hill	Antiq. J. 1923, 3, 374.	R?	S.
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Romano-British Ironworking Sites, a Gazetteer

Andrew R Aiano ©

General Introduction

The importance of the study of technology, in as much as it represents the means whereby human socieities not only utilize, but also modify, the resources of their environment to meet their needs, is an established axiom in archaeology[1]. Technologists also have for some time been aware of the significance of their subject: 'Social and economic history are, as it were, the flesh and blood for which technology is the supporting skeleton'[2]. Classicists, on the other hand, appear to have dragged their feet in this respect – Kennedy (of Latin Grammar fame), for example, is reputed to have held the opinion that science was an unrelated heap of trivial facts. The position has, of course, now changed; yet Forbes,[3] writing as recently as 1950, complained about the antithesis of the two disciplines, 'arts' and 'science':

'For only too often the story of metallurgy, that important factor in ancient material civilization, has been neglected. Which of our large handbooks either archaeological or technical contains more than generalities in this subject, and only too often wrong facts that are taken over from one handbook into another? How few are the books on ancient history whose table of contents contains references to metals or metallurgical products as if these never played a part in political history in those times as they do now! And again, why is not the proper technical and scientific information available to the archaeologist and are his data not presented in the proper context to the technologist, who is usually put off with old, superannuated facts?'

Forbes directs his criticism not just at the dichotomy between arts and science but also at the quality of research in the field of metallurgy. When one realizes that we have no written record of Roman iron-making processes[4], then perhaps there is some excuse for the kind of fallacies in iron-metallurgy that can be found in the works of early technologists[5] and archaeologists, as will be seen later. (In fact, the Romans viewed the skill of iron production as a valuable trade secret to be revealed only to apprentices). Fortunately for us, however, the laws of science operated in exactly the same way during Roman times as they do now, and it has been possible, through extensive experimentation with reconstructed furnaces[6], to discover some of the secrets of iron-making. The knowledge thus gained about the scientific aspects of the process has facilitated the interpretation of data which early archaeologists found perplexing. Over the past few years more information has become available from industrial and other sites of Roman date. It is therefore to be hoped that this collation of the evidence from Roman iron-working sites will be of help in creating a clearer picture of the Romano-British iron industry.

Technical Introduction

A Roman Iron Metallurgy

'There is a confusion about what is meant by 'iron' and 'steel'. Naturally in both cases the predominant chemical element is iron. 'Iron' by itself usually means iron in the relatively pure chemical form. 'Cast iron' on the other hand means iron containing nearly as much carbon as it will hold, perhaps about four per cent. 'Wrought iron' is different again and is usually a special sort of fairly pure iron containing glassy inclusions. 'Steel' usually means iron with a little carbon in it, generally less than one per cent'[7].

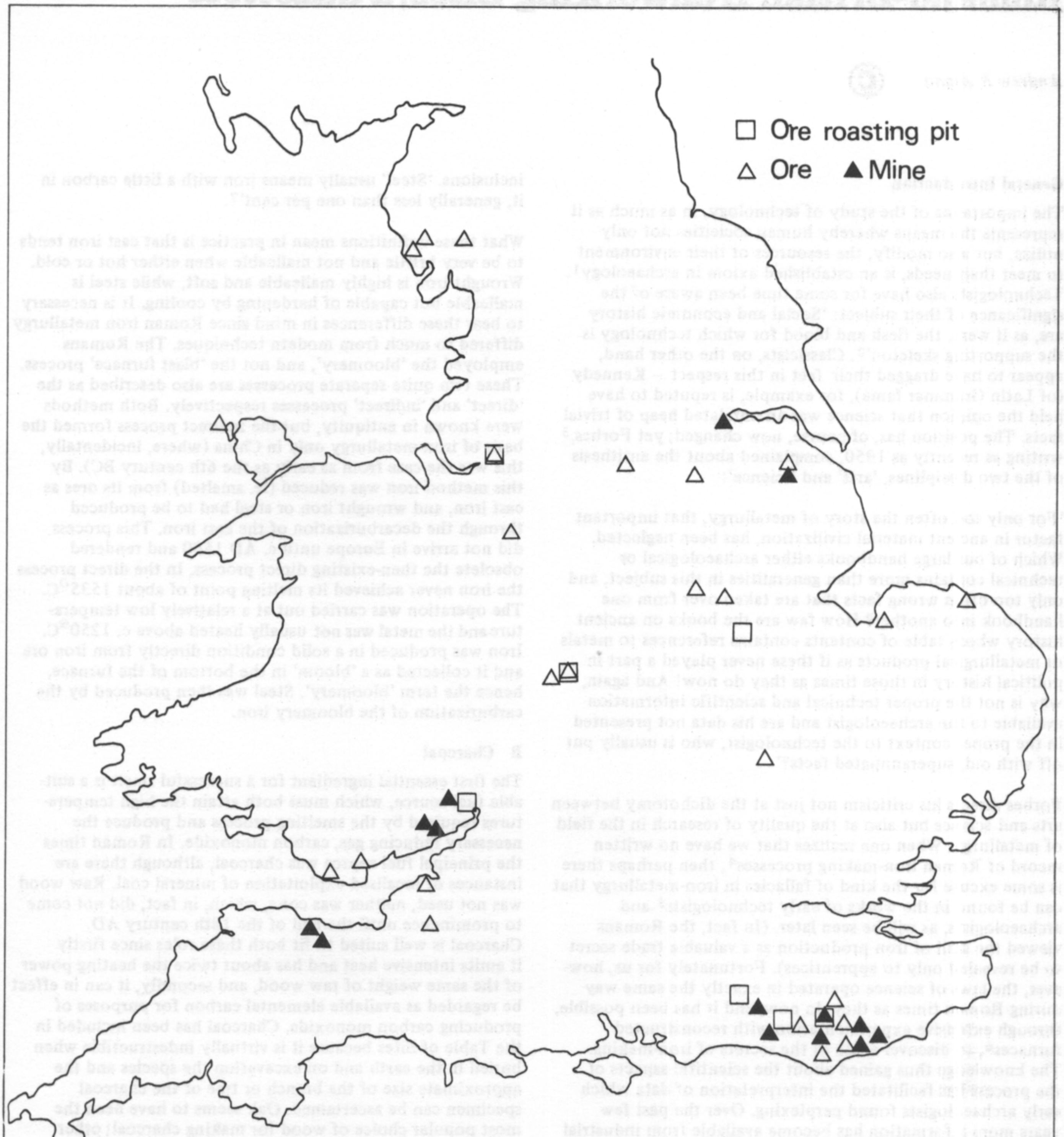
What these definitions mean in practice is that cast iron tends to be very brittle and not malleable when either hot or cold. Wrought iron is highly malleable and soft, while steel is malleable but capable of hardening by cooling. It is necessary to bear these differences in mind since Roman iron metallurgy differed so much from modern techniques. The Romans employed the 'bloomery', and not the 'blast furnace' process. These two quite separate processes are also described as the 'direct' and 'indirect' processes respectively. Both methods were known in antiquity, but the indirect process formed the basis of iron metallurgy only in China (where, incidentally, this was the case from as early as the 6th century BC). By this method iron was reduced (ie. smelted) from its ores as cast iron, and wrought iron or steel had to be produced through the decarburization of the cast iron. This process did not arrive in Europe until c. AD 1500 and rendered obsolete the then-existing direct process. In the direct process the iron never achieved its melting point of about 1535°C. The operation was carried out at a relatively low temperature and the metal was not usually heated above c. 1250°C. Iron was produced in a solid condition directly from iron ore and it collected as a 'bloom' in the bottom of the furnace, hence the term 'bloomery'. Steel was then produced by the carburization of the bloomery iron.

B Charcoal

The first essential ingredient for a successful smelt is a suitable fuel source, which must both attain the high temperatures required by the smelting process and produce the necessary reducing gas, carbon monoxide. In Roman times the principal fuel source was charcoal, although there are instances of localised exploitation of mineral coal. Raw wood was not used, neither was coke, which, in fact, did not come to prominence until the end of the 18th century AD. Charcoal is well suited to fit both these roles since firstly it emits intensive heat and has about twice the heating power of the same weight of raw wood, and secondly, it can in effect be regarded as available elemental carbon for purposes of producing carbon monoxide. Charcoal has been included in the Table of Sites because it is virtually indestructible when buried in the earth and on excavation the species and the approximate size of the branch or tree of the charcoal specimen can be ascertained. Oak seems to have been the most popular choice of wood for making charcoal; other woods discovered on smelting sites include beech, hazel, maple and ash.

C Ore

Of the two methods of obtaining iron, reduction from its ores was the more common procedure among the Romans, although it is possible that the manufacture of iron objects from telluric or meteoric iron (ie. iron occurring in its natural state) was carried out on an extremely limited scale[8]. Both the oxide (hematite and magnetite) and the carbonate (siderite and its varieties) categories of iron ore were known to and exploited by the Romans. It is unlikely, however, that they used the sulphide group (iron pyrites) because the presence of sulphur in it has a detrimental effect on the iron produced.



General distribution map illustrating the sites in England and Wales where mines, ore and ore-roasting pits have been found.

D Mines

Just over 5% of the earth's crust is iron and indeed it is second in quantity only to aluminium. Pliny[9] was correct, then, when he stated that 'Iron ores occur in greater abundance than those of any other metal'. To say that iron has a world-wide distribution is to oversimplify the situation; quality and ease of obtaining the ores are also factors to be taken into account. Nevertheless, this ubiquity of iron ensures that the ore deposits usually have outcrops occurring at or near the surface of the ground. The majority of known mines were worked by opencast methods: once ore-bearing strata had been discovered they would have been exploited by sinking pits, which were then abandoned after the extraction of the ore. Such pits found in the Weald were up to 24m across by 15m deep, tapering towards the bottom. They were shaped more like pudding-basins than the later 'bell-pits' of Medieval date. As for underground working, at present only one authenticated instance is known of a Roman underground iron mine. Wheeler[10] excavated a 3rd century AD iron mine at Lydney Park in Gloucester, where, in the not unreasonable hope of finding an ore-body, a passage c. 0.6m wide had been dug to follow a band of ferruginous marl. The difficulties of the location of Roman mines, summed up by Davies[11] below, explain why so few iron mines have been discovered:

'The evidence for ancient mines is in all cases poor, and archaeologists must not demand so strict a standard as in other branches . . . I have often had to rely on vague reports and surface finds, which cannot prove securely the date of a mine as they may have been dropped accidentally . . . Later work may sometimes have destroyed the traces of earlier; but archaeology demands concrete proof before the existence of the earlier can be upheld'

E Features

The current understanding of remains at iron-working sites has led to the differentiation of features into three groups: 1. ore-roasting pits, 2. smelting furnaces, 3. smithing hearths. However, it is not always possible to categorize site features into these groups because of the looseness of language that is to be found in some archaeological reports. For example, ore-roasing pits are also described as 'hearths' or 'troughs'. Smelting furnaces vary from 'bowl-furnaces' (which in early literature are most probably ore-roasting pits) to 'smelting floors', and the structure for smithing can either be a 'furnace' or a 'hearth'. Further, furnace bottoms are sometimes referred to as 'Hearths'. The lack of more definite detail has necessitated a fourth grouping in the Table of Sites, that of the 'unidentified feature'.

1. ore-roasting pits:

Prior to the smelting operation, ore was washed and roasted. Roasting took place in pits or troughs, and was an indispensible process since it removed the water that was chemically combined with the oxide in the ore and improved the percentage weight of the iron in the ore. It also either broke the ore down directly, or rendered it liable to be shattered into pieces of suitable size for smelting.

2. smelting furnaces:

The iron smelting process involves a chemical reaction between the ore and the fuel to separate the iron from the oxygen in the iron oxide ore (iron carbonate ores are converted to the same chemical composition as the oxide ores by roasting). For a detailed exposition of the smelting operation the reader is referred to Tylecote[12] or Aiano[13]. The problems of identification and classification of iron smelting furnaces have been fully covered by Cleere[14] and they do not warrant repetition here.

3. smithing hearths:

The identification and classification of smithing hearths, on the other hand, is an area of study that is till in its infancy. A smithing hearth need not be an elaborate affair nor indeed a permanent one: all that is required is a pair of bellows and a pile of charcoal. Bestwick and Cleland[15], who are at present attempting to compile details of smithing hearths with the aim of providing a satisfactory classification, have found the task a difficult one:

'. . . It should be apparent that more recording of details is necessary when hearths are excavated. Many such hearths have been excavated but have been summarily dismissed as 'hearths' or 'bowl-furnaces'. Consequently there is a grave lack of material in so far as classification is concerned'.

The **smithing** stage was the first stage of working the bloom after it had been removed from the furnace. A bloom direct from the furnace is a mixture of iron and residual slag (for descriptions of slags see below). The entrapped slag was squeezed out mechanically by hammering at a high temperature, c. 900°C. When the impurities had thus been removed from the bloom, **forging** was necessary to turn it into workable iron. The skill involved in forging lay in converting the bloom into metal of the most useful condition of hardness, strength and toughness.

At a number of sites blooms have been found at various stages of working; these are shown in the Table of Sites as iron giving evidence of smelting or smithing.

F Slags

'Slag' is another term that appears to be applied with some looseness. It is important, therefore, to grasp exactly what is meant by the term. The word, in fact, covers three separate types of iron metallurgical dross: 1. tap slag, 2. cinder, 3. smithing slag or cinder, and scale.

1. tap slag:

Iron ores do not occur as pure minerals in their natural state but contain unwanted stony matter (such as clay, limestone or sand) known as 'gangue'. Since it is not practicable to remove much of this gangue from the ore by washing, it must be separated during the smelting process by 'slagging'. As reduction of the ore proceeds, slag forms from the gangue and collects in the bottom of the furnace. Slag has a relatively low melting point and can easily be removed from the iron by liquation. Tap slag, then, is the slag which has been removed by 'tapping', through the front of the furnace, in a semi-liquid state. The presence of tap slag at a site positively indicates the presence of a smelting furnace.

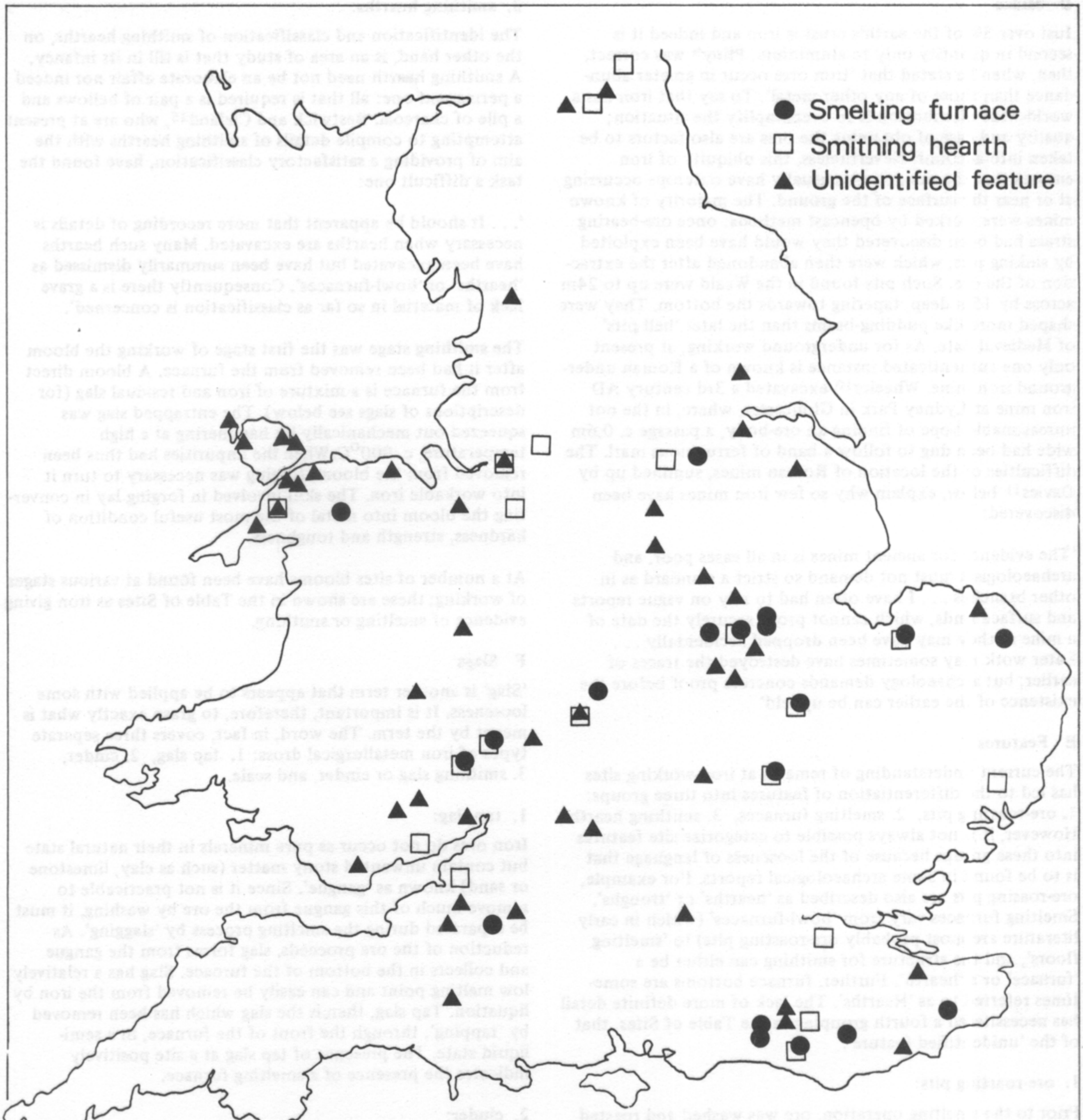
2. cinder:

While slag is molten at the completion of the smelting process, cinder has never reached the molten or 'free-running' condition. Cinder is the solid drossy material that remains in the furnace and can be distinguished visually from slag by its definite 'cindery' appearance.

3. smithing slag or cinder, and scale:

The two stages of working-up the bloom, smithing and forging, both produce dross. Smithing slag or cinder is the by-product of the smithing stage and it resembles cinder from smelting:

'It is difficult to distinguish between slags and cinders produced by smelting and cinders produced by smithing without a complete metallographic examination and chemical analysis'[16].



General distribution map illustrating the sites in England and Wales where smelting furnaces, smithing hearths and unidentified features have been found.

The forging stage produces hammer scale.

It will be evident from the above that the identification of 'slag' from iron-working sites is a complex subject. It is not surprising, therefore, that many excavation reports do not specify the type of slag found. Likewise, the term 'slags' in the Table of Sites does not discriminate between the various types of slag.

G Unspecified sites and Dates

The Table of Sites contains two other aspects of Roman iron-working. The first is the category 'unspecified sites'. This has been included because some archaeological journals carry only summary reports of excavations until full details are published. Thus, the precise nature of the site has not yet been revealed but left couched in some such words as 'evidence of iron-working'. In addition, early archaeologists did not have any metallurgical information at their disposal, and, consequently, their reports are often quite meaningless.

Secondly, when possible the precise date of the iron-working remains at sites has been given. The Roman period of occupation in general is referred to where no date is given, and the category 'R?' covers tentative or doubtful Roman dating.

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Gazetteer

TABLE OF SITES SHOWING ROMANO–BRITISH IRON–WORKING REMAINS

C = charcoal
O = ore
M = mine
OR = ore-roasting pit
F = smelting furnace
H = smithing hearth
UF = Unidentified feature
I = iron giving evidence of smelting or smithing
S = slags
U = unspecified site

The sites have been arranged alphabetically by old counties.

Site	Reference	Date AD	Remains
ENGLAND			
Berkshire			
Bray	Britannia 1970, p.302		S
Cox Green	J. Roman Stud., 1960, p.233	C2–4	S
Silchester	G. Boon: 'Silchester', David & Charles, 1974, p.267f.	C1	I.S.
Thatcham	J. Roman Stud. 1928 p. 207.		U
Buckinghamshire			
Hambleden Valley	Archaeologia, 1920–1, 71, 152f.	C1–4	UF.S.
Stanton Low	R. F. Tylecote: 'Metallurgy in Archaeology', London, 1962, p. 218.		I.S.

Site	Reference	Date AD	Remains
Cheshire			
Heronbridge	J. Chester North Wales Architect. Archaeol. Hist. Soc. 1954, 41, 10. Tylecote: op. cit. p.218.	C1	C.S.
Middlewich	J. Roman Stud., 1969, p. 211. Britannia 1973,p.284. Britannia 1974,p.419.	C2–4	H.S.
Northwich	J. Roman Stud., 1969, p. 209. Archaeol. J. 1971,128, 43ff. Britannia 1973,p.284.	C2	UF.S.
Cumberland			
Eskmeals	Trans. Cumberland Westmorland Antiq. Archaeol. Soc. 1966. 66, 46ff.		O.S.
Forest Howe	Trans. Cumberland Westmorland Antiq. Archaeol. Soc. 1922. 22, 92.	R?	O.U.
Muncaster Head	Trans. Cumberland Westmorland Antiq. Archaeol. Soc. 1922, 22, 93.	R?	C.S.
Derbyshire			
Derby	Britannia 1975,p.243		UF
Scarcliffe Park	Britannia 1971,p.256	R?	C.UF.S.
Dorset			
Colliton House	J. Roman Stud., 1939 p.219.	C2	S.
Poundbury	Britannia 1971,p.281 Britannia 1973,p.316	C3	U.
Durham			
Binchester Fort	Britannia 1972,p.309		U
Chester-le-Street	J. Roman Stud., 1964 p.156	C3	U.
Essex			
Colchester	J. Roman Stud., 1931, p. 235		U.
Heybridge	Britannia, 1973,p.305	C2	C.S.
Old Harlow	Britannia, 1971,p.289		U
Gloucestershire			
Cirencester	Britannia, 1974,p.448		UF.S.
Dymock	Britannia,1970,p.293 Britannia, 1972,p.339	C2–4	F.H?.S.
Lechlade	J. Roman Stud., 1958, p. 144.		UF.
Lower Slaughter	Bull. Hist. Metall. Group 1966, 7, 30ff.		I.
Forest of Dean			
Bream Scowles	Bull. Hist. Metall. Group 1968, 2 (1), 28.		M.
Cinderford Ridge	Trans. Bristol Gloucestershire Archaeol. Soc., 1956, 75, 202.		M
Hentland	Bull. Hist. Metall. Group 1968, 2 (1), 29.	R?	S.
Llancloudy	Bull. Hist. Metall. Group 1968, 2 (1), 29.	R?	S.
Lydney Park	R.E.M. & T.V. Wheeler: Soc. Antiq. London Report No.9. 1932, p. 18ff Bull. Hist. Metall. Group 1968. 2 (1), 29.	C3	M.
Peterstow	Bull. Hist. Metall. Group 1968. 2 (1), 29.	R?	S.
Popes Hill	Trans. Bristol Gloucestershire Archaeol. Soc. 1956. 75, 200 & 202. Bull. Hist. Metall. Group 1968. 2 (1), 30.		OR.UF.S.
Staunton	Bull. Hist. Metall. Group 1968, 2 (1), 30.	R?	S.
Tretire	Bull. Hist. Metall. Group 1968, 2 (1), 30.	R?	S.
Whitchurch	Bull. Hist. Metall. Group 1968. 2 (1), 30.	R?	S.
Wigpool Common	Bull. Hist. Metall. Group 1968. 2 (1), 27.	R?	S.
(see also Monmouth and Ariconium)			
Hampshire			
Neatham	Britannia 1975,p.216.		U
Herefordshire			
Ariconium	Trans. Woolhope Natur. Fld. Club 1923, Appendix, G. Jack: 'Excavations on the site of Ariconium'. J. Roman Stud., 1964, p. 165. Trans. Woolhope Natur. Fld. Club, 1965, 38 (2), 124ff. Bull. Hist. Metall. Group 1968, 2 (1), 29.	C2–4	C.F.H.I.S.
Hertfordshire			
Puckeridge	Britannia, 1973,p.299	C3	U.
Huntingdonshire			
Godmanchester	J. Roman Stud., 1965, p. 209 Britannia, 1973,p.289.	C3	F.H.

Site	Reference	Date AD	Remains
Sacrewell Villa	Britannia, 1975,p.253	C4	F.H.O.
Kent			
Brenley Corner	Britannia, 1973,p.322		UF.S.
Cranbrook	Archaeol. Cantiana, 1958. 72, p.XLVII & LXff J. Roman Stud., 1960, p. 235.	C1–2	S.
Richborough	J. Roman Stud., 1921, p. 223		S.
Springhead	J. Roman Stud., 1969, p. 232. Britannia, 1971,p.288 Britannia, 1973, p. 323	C1–2	H.S.
Wye	Britannia, 1971,p.288	C1–3	F.
Lancashire			
Manchester	G.D.B. Jones and S. Grealey: 'Roman Manchester', Sheratt, 1974, p. 67ff and 143ff.	C2	H.
Quernmore	Britannia, 1973, p.283		UF.
Warrington (including Wilderspool)	T. May: 'Warrington's Roman Remains', Warrington, 1904, p. 18ff. Irona nd Coal Trades Review, Aug. 1905, p. 427ff.		C.O.OR. H.UF.S.
Lincolnshire			
Ancaster	Britannia, 1971,p.257	C2	U.
Bagmoor	H. Dudley: 'Early Days in North West Lincolnshire', Scunthorpe, 1949, p. 184ff.		M?UF.
Claxby	Mining, 1896. p.734		C.O.S.
Colsterworth	Antiq. J. 1932, 12, 262ff. J. Roman Stud., 1933, p. 196.	C2	C.O.UF.S.
Scunthorpe	Tylecote, op.cit.p.218	R?	S.
Thealby	Dudley, op.cit. p.194ff		M?.UF.S.
Winterton Villa	Britannia, 1974,p.424		U.
Norfolk			
Ashwicken	Norfolk Archaeol. 1960, **32**, 142ff.	C2	C.O.F.H. S.
Aylesham	Tylecote op.cit.p.218		S.
Beeston Regis	Archaeol. J. 1933, **40**, 285f. V.C.H. Norfolk **1**, p. 313.		O.UF.S.
Brampton	J. Roman Stud., 1969, p. 223. Britannia, 1970,p.290	C2–3	F.
Hevingham	Tylecote op. cit. p.218		S.
Wormegay	Geological Survey Memoirs 1893 p.147.		S.
Northamptonshire			
Ashton	Britannia, 1975,p.254.		UF. S.
Bulwick	Archaeologia, 1871, **43** (1), 118. D.A. Jackson: private communication.		
Castor (including Bedford Purlieus and Wansford)	E. Artis: 'The Durobrivae of Antoninus', London, 1828. Plate 1. J. Roman Stud., 1963, p.135. J. Roman Stud., 1966, P.207. Bull. Hist. Metall. Group 1968, 2 (2), 66f.	C2–3	C.OR.S.
Colley Weston	J. Roman Stud., 1955, p. 134.	C1–4	UF.S.
Great Weldon	J. Roman Stud., 1954, p. 95.	C2	UF
Irchester	Archaeol. J. 1878, **35**, 269.		S.
Kettering	Archaeol. J. 1878, **35**, 269.		S.
King's Cliffe	Archaeol. J. 1878, **35**, 269.		S.
Laxton	Archaeol. J. 1878. **35**, 269.		S.
Oundle	Archaeol. J. 1878, **35**, 269.		S.
Rockingham	Archaeol. J. 1878, **35**, 269.		S.
Scaldwell	J. Roman Stud., 1926, p. 223.	R?	U.
Syresham	J. Roman Stud., 1926, p. 223.	R?	UF
Wakerley	Britannia 1973,p.294 Britannia 1974,p.434		F
Northumberland			
Chesterholm Fort	Britannia, 1973,p.275	C4	UF
Corbridge	Archaeol. Aeliana 1912, 3rd Series, 8, 150 and 158.		H.I.
Halton	J. Roman Stud., 1959 p. 106.		UF.
Housesteads	Archaeol. Aeliana, 1904. **25**, 241.		S.
Huckhoe	Archaeol. Aeliana, 1959, **37**, 236 & 267.	C2	H.S.
Nottinghamshire			
Gringley-on-Hill	Tylecote op.cit. p.218	C4	O.S.

Site	Reference	Date AD	Remains
Margidunum	J. Roman Stud. 1923, p.115. Trans. Thoroton Soc. Nottinghamshire, 1927, 31, 66. J. Roman Stud., 1967, p. 183.	C1	O.UF.S.
Oxfordshire			
Bloxham	J. Roman Stud., 1924, p. 229.		U.
Callow Hill	Oxoniensia,1957, 22, 51.		S.
Milton Common	Britannia 1972, p.328	C3–4	U.
Wilcote	J. Roman Stud. 1964, p. 166.		U.
Woodeaton	J. Roman Stud. 1917, p. 100		S.
Woodperry	J. Roman Stud. 1917, p. 100.		S.
Rutland			
Clipsham	J. Roman Stud. 1926, p. 223.		C.S.
Great Casterton	P. Corder: 'The Roman Town and Villa at Great Casterton', University of Nottingham, 1951, p.19 & 41f.	C1–2	F.S.
Pickworth	J. Roman Stud. 1962, p. 173.	C2	F.S.
Shropshire			
Wroxeter	D. Atkinson: 'Report on Excavations at Wroxeter', Oxford, 1942, p. 108f. Britannia 1974, p.429.	C4	UF.S.
Somerset			
Bradley Hill	Britannia 1970, p.295f		S.
Brislington	Trans. Bristol Gloucestershire Archaeol. Soc. 1900. 23. p.298. V.C.H. Somerset 1 p. 305.		S.
Butcombe	J. Roman Stud. 1968 p. 198.	C1	U.
Camerton	Tylecote op. cit. p.219	C2	F.S.
Cheddar	Britannia 1971, p.278	C1–2	U.
Chew Stoke (including Herriot's Bridge)	J. Roman Stud., 1955 p. 139. Proc. Somerset Archaeol. Natur. Hist. Soc. 1956–7. **101–2**, 28f.	C3	UF.S.
Clapton-in-Gordano	J. Roman Stud. 1924, p.235.		O.S.
Combe Hay	Britannia 1970, p.296.	C2	UF.
Gatcombe	Britannia 1970, p.296. Britannia 1974, p.452.	C3	H.S.
Green Ore	J. Mendip Nature Research Committee 1970 Report on Vespasian Farm p. 6f.	C1–2	O.UF.S.
Ilchester	J. Roman Stud. 1968, p. 199.	C3–4	UF.
Luccombe	Archaeol. J. 1895, **52**, 38f.	R?	M.
Luxborough	Archaeol. J. 1879, **36**, 327. Archaeol. J. 1895. **52**, 38.		M.
Mells	J. Roman Stud. 1929 p. 204. Archaeologia 1930, **80**, 86.		S.
Treborough	Archaeol. J. 1879, **36**, 327.		U.
Yatton	V.C.H. Somerset 1, p. 307.	R?	S.
Staffordshire			
Holditch	J. Roman Stud. 1959, p. 112.	C1	C.O.S.
Shenstone	J. Roman Stud. 1965, p. 207.	C3–4	U.
Suffolk			
Hacheston	Britannia 1974, p.439.	C3C	H.
Sussex			
Bardown	E. Straker: 'Wealden Iron', David & Charles Reprint, 1969, p. 296. H. Cleere: 'The Romano-British Industrial Site at Bardown, Wadhurst, Sussex', Sussex Archaeol. Occ. Paper No. 1, 1970. Archaeol. J. 1974, **131**, 190f.	C2	M.OR.S.
Beauport Park	Straker op. cit. p.330 Britannia 1972, p.350. Archaeol. J. 1974, **131**, 191f.	C2–3	S.
Blacklands Farm	Sussex Archaeol. Collect. 1862. **14**, p. XIII.	R?	S.
Crowhurst Park	Straker op. cit. p.353 Sussex Archaeol. Collect. 1938, **79**, 224ff. Archaeol. J. 1974, **131**, 193.	C1–3	C.M.S.
Doozes Farm	Archaeol. J. 1974, **131**, 194.		O.S.
Footlands	Straker op. cit. p. 327. Archaeol. J. 1974, **131**, 194.		C.S.

Site	Reference	Date AD	Remains
Great Cansiron	Sussex Archaeol. Collect. 1972, 110. p. 10ff. Archaeol. J. 1974, **131**, 194.		S.F.
Hartfield	Britannia 1973 p. 321 and 333. Bull. Hist. Metall. Group 1973, **7** (1), 41. Britannia, 1974, p.458.	C2	UF.S.
Holbeanwood	Cleere op. cit. p. 11. Bull. Hist. Metall. Group 1971, **5** (1), 39. Archaeol. J. 1974, **131**, 195.	C1–3	O.F.S.
Howbourne Farm	Straker op. cit. p. 390 Archaeol. J. 1974, **131**, 195.		S.
Icklesham	Archaeol. J. 1974, **131**, 195.		UF.S.
Knowle	Bull. Hist. Metall. Group 1970, **4** (1), 18ff. Archaeol. J. 1974, **131**, 195.	C2–3	O.S.
Limney Farm	Straker op. cit. p.387 Archaeol. J. 1974, **131**, 196.	R?	S.
Little Inwoods	Bull. Hist. Metall. Group 1970. **4** (1), 18ff. Archaeol. J. 1974, **131**, 196.	C1	S.
Ludley Farm	Sussex Archaeol. Collect. 1973, **111**, 111. Archaeol. J. 1974, **131**, 196.	C2	M?.S.
Magreed Farm	Bull. Hist. Metall. Group 1970, **4** (1), 18ff. Archaeol. J. 1974, **131**, 196.		S.
Minepit Wood	J. Roman Stud. 1964, p. 177. J. Roman Stud. 1967, p. 200. Archaeol. J. 1974, **131**, 196. J. Hist. Metall. Soc. 1974, 8 (1), 1ff.	C1	C.H.S.
Morphews	Archaeol. J. 1974, **131**, 197.		S.
Oakenden Farm	Archaeol. J. 1974, **131**, 197.		C.M?.S.
Oaklands Park	Straker op. cit. p. 329. Archaeol. J. 1974, **131**, 197.		S.
Oldlands	Sussex Archaeol. Collect. 1849, 2, 169ff. Straker op. cit. p. 395. Archaeol. J. 1974, **131**, 197.		S.
Pepperingeye	Straker op. cit. p. 351 Archaeol. J. 1974, **131**, 198.		S.
Petley Wood	Archaeol. J. 1974, **131**, 198.		M.
Pippingford	Sussex Archaeol. Collect. 1973, **111**. p. 27ff. Archaeol. J. 1974, **131**, 198.		OR?. F.H.S.
Pounsley	Archaeol. J. 1974, **131**, 198.		S.
Ridge Hill	J. Roman Stud. 1927, p. 209. Sussex Archaeol. Collect. 1928, **69**, 183. Straker op. cit. p. 233. Archaeol. J. 1974, **131**, 199.		UF.S.
Shoyswell Wood	Archaeol. J. 1974, **131**, 199.	R?	O.S.
Stricked-ridge Gill	Archaeol. J. 1974, **131**, 199.	R?	M.S.
Walesbeech	Straker op. cit. p.239 Archaeol. J. 1974, **131**, 199.		M.S.
Warwickshire			
Stratford-on-Avon	J. Roman Stud. 1925, p.231. J. Roman Stud.1927, p. 200.		C.O.H. UF.S.
Tiddington	W. Fieldhouse et al. : 'The Romano-British Industrial Settlement near Tiddington'. Birmingham, 1931, p. 8ff.		O.OR.F. S.
Westmorland			
Ambleside	Trans. Cumberland Westmorland Antiq. Archaeol. Soc. 1902, 2, 34.	R?	C.O.I.
Watercrook Fort	Britannia 1975, p.234.		S.
Wiltshire			
Baydon	Wiltshire Archaeol. Natur. Hist. Mag. 1866–7, **10**, 107f.		I.S.
Worcestershire			
Droitwich	Trans. Birmingham Archaeol. Soc. 1941, 64, 44.		S.
Worcester	Archaeol. J. 1895, 52, 40. Mining J. 1896. p.822.		UF.S.
Yorkshire			
Bierley	Bradford Antiq. NS 3. p. 435.		S.

Site	Reference	Date AD	Remains
Brough-by-Bainbridge	J. Roman Stud. 1969, p. 207.	C4	S.
Doncaster	Yorkshire Archaeol. J. 1956, 39, 32ff.		C.F.S.
Elmswell	J. Roman Stud. 1938, p. 179. J. Roman Stud. 1939, p. 204.	C4	S.
Holme-upon-Spalding Moor	Britannia 1972, p.310	C4	UF.
Temple-borough	T. May: 'The Roman Forts of Templeborough', Rotherham, 1922. p. 57f.		O.H.S.
SCOTLAND			
Dunbartonshire			
Bar Hill	G. Macdonald & A. Park: 'The Roman Forts on the Bar Hill, Glasgow, 1906. p. 44.		I.S.
Fife			
Constantine's Cave	Proc. Soc. Antiq. Scotland, 1914–5, 49, 241f.	C2	UF.I.S.
Lanarkshire			
Croy Hill	Proc. Soc. Antiq. Scotland 1931–2, 46, 251.		S.
Midlothian			
Castlelaw Fort	Proc. Soc. Antiq. Scotland 1932–3, 47, 382ff.	C2	I.S.
Perthshire			
Carpow	J. Roman Stud. 1968, p. 177.	R?	S.
Inchtuthil	J. Roman Stud. 1961, p. 160.		H.S.
Renfrewshire			
Bishopton	J. Roman Stud. 1955, P. 123.		I.S.
WALES			
Anglesey			
Aberffraw	Britannia 1974, p.397.		U.
Coed Newydd, Penrhos Lligwy	Archaeol. Cambrensis 1920, p. 91f.		C.UF.I.S.
Din Lligwy	Archaeol. Cambrensis, 1908, p. 197f.	R?	C.UF.S.
Pen-y-bonc	Archaeol. J. 1870, 27, 151.		C.UF.S.
Ty Mawr	Archaeol. J. 1896, 26, 301ff.		O.UF.S.
Brecknockshire			
Aberllynfi	Brycheiniog, 1958, p. 63f.	C1–2	C.UF.S.
Caernarvonshire			
Bryn-y-Gefeiliau	Archaeol. Cambrensis, 1948, p. 90ff.	R?	C.F.S.
Dinas Emrys	Bull. Board Celtic Stud. Nov. 1954, p. 52f.	C1	C.S.
Graeanog	J. Roman Stud. 1960, p. 211.		UF.
Llanddeiniolen	Archaeol. Cambrensis, 1922, p. 336.	R?	UF.
Penmaenmawr	Archaeol. Cambrensis, 1913, p. 359.	R?	I.U.
Rhostryfan	Archaeol. Cambrensis, 1923, p. 87ff and 295ff.	C3	C.H.UF.S.
Tregarth	Archaeol. Cambrensis, 1922, p. 336.	R?	UF.
Cardiganshire			
Llanio	Britannia, 1970, p.269.		S.
Carmarthenshire			
Cwmbrwyn	Archaeol. Cambrensis, 1907, p. 199.		C.S.
Denbighshire			
Kinmel Park	Archaeol. Cambrensis, 1913, p. 194.	C4	UF.S.
Glamorganshire			
Bolston Gaer	R.E.M. Wheeler: 'Prehistoric and Roman Wales', Oxford, 1925, p. 272.	R?	S.
Ely	Cardiff Natur. Soc. Trans. 1893–4 26, 129. J. Roman Stud. 1921, p. 79f.		O.UF.S.
Llantwit Major Villa	Archaeol. Cambrensis, 1953, p.129 & 157.	C2–3	S.
Llechau	Wheeler op. cit. p.272.	R?	U.
Ty Isaf	Wheeler op. cit. p.272.	R?	U.
Monmouthshire			
Caerleon	Archaeol. Cambrensis, 1936, p. 321. J. Roman Stud. 1937, p. 224. Britannia, 1970,p.272.	C1	C.S.
Caerwent	Archaeologia, 1901, 57,(2), 300. J. Roman Stud. 1948, p. 81.	C2	H.S.

Concluded on page 72

The Downpatrick Bloom

JHMS 11/2 1977

R F Tylecote ©

The Downpatrick bloom was excavated in the 1950's by Dr Bruce Proudfoot, then of Queen's University, Belfast. It came from a 13th century level of the hill fort at Downpatrick, in Co. Down, Ulster. It was reported by Schubert in his history[1], p. 140, as being a 'rectangular oblong piece of iron 2 x 2 x 8 inches showing marks of cutting with a sharp tool, weighs a fraction more than 1 lb 7 ½ oz . . . . The piece is much corroded, which accounts for it weighing less than 2 lb. Quarrels, i.e. iron bolts for crossbows made for the Royal Castle of Ayr in Scotland in 1264–66 weighed 1¾ lb each, **The Exchequer Rolls of Scotland**, vol. 1, pp 5–6, Edinburgh 1878. Allowing for loss in forging, the piece would have weighed about 2 lb'

Schubert also gives an analysis of the material in his Appendix 1, p. 340. This was carried out by The British Cast Iron Research Association who report that the bloom contained rather a large amount of 'slag' inclusions; magnetic separation gave a value of 7.25% non-magnetic material ('slag') which does not include the corrosion product on the outside of the bloom.

The composition of the slag-free metal was:–

C 0.08% Si 0.16 Mn 0.02 S 0.038 P 0.061

There is little doubt that it is the product of charcoal smelting a low phosphorus ore. The site provided evidence of tap slag and traces of furnaces and it is probable that the bloom is a product of local smelting. Dr Proudfoot thinks that the ore may have been the highly weathered ferruginous material of Silurian date that he found on the site.

The bloom was sent to me in three pieces for macro and micro-examination. The pieces had been cut as shown in Figure 1, presumably by BCIRA. The chemical analysis had been made on drillings taken from the area shown. Figure 2 shows the macro-structure of the surface exposed by the second cut CD.

Its present weight is now exactly 500 g which equals 1.10 lb, which is more or less in keeping with its original weight of 1 lb 7½ oz (1.47 lbs) when account is taken of the material removed by cutting and drilling. But the length of 8 in must be in error as it is now nearly 4.5 in long and it is unlikely to have been much bigger if its weight is anywhere near correct. It would appear then that Schubert's 8 in is a mistake for 5 in. The actual dimensions noted during a discussion with Dr Proudfoot in June 1960 confirm the figure of 4.5 in.

Macro-examination shows, as expected iron and slag. Hardness readings across the section AB gave results varying from 123 to 161 HV5 on the iron phase only (Figure 2).

Micro-examination of a small piece cut from this section (position shown in Figure 1) showed the presence of ferrite and slag and gave a hardness of 137 HV. These hardness figures are a little high for pure phosphorus-free ferrite and indicate the presence of some carbide or nitride. In view of the low carbon figure given in the analysis, I would expect there to be some nitrogen present which is quite a common impurity in bloomery iron.

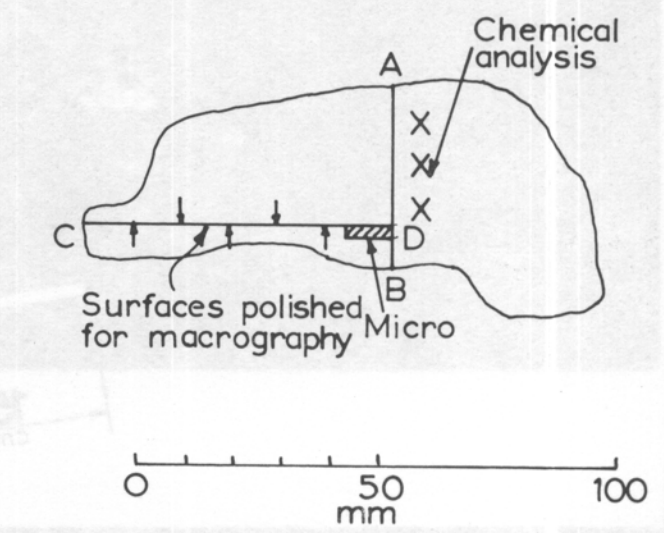


Fig 1

Acknowledgements

I am grateful to Dr Proudfoot for discussion and to Dr G T Brown for his help with the microscopy.

Reference

1 H R Schubert. History of the British Iron and Steel Industry. London, 1957, p. 140.

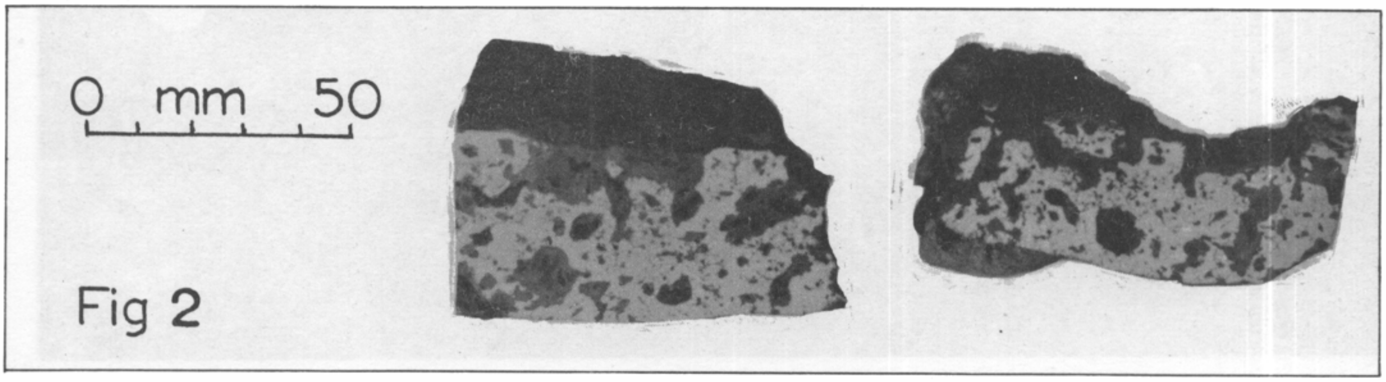
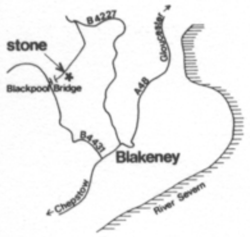


Fig 2

The Drummer Boy Stone, Forest of Dean, Gloucestershire

I J Standing and R F Tylecote



Location

The stone is situated at NGR SO 655090 This is some 2.5 km northwest of Blakeney, Gloucestershire. The stone lies on the bank of a small tributary of the Blackpool Brook. A few metres to the west, the ancient Dean Road passes the stone, as does the present road.

History

The stone is of interest in that it has two hollows on its surface, one of which contains a dark coloured hard shiny substance which looks superficially similar to bloomery slag. This deposit has been described as 'iron', 'smelted iron' and 'smelted iron ore', by various authors. .

The early history of this stone is obscure. An extensive literature search reveals no reference until Trotter, 1936, who described it in some detail on account of its proximity to the Dean Road.[1] He dug around the stone to ascertain its depth and reports 'a number of pieces of clinker at 18 ins depth.' He noted a stone close by which appears also to have natural hollow on its top.

Trotter refers to another stone, which lay ½ km to the north, known as the Pattern Stone. This was recorded on large scale OS maps and is shown on the latest 1:25000 OS map. The Drummer Boy Stone is not recorded at this scale. Trotter reports that he made several fruitless searches for this stone before discovering that it had been removed in 1922 when the Crown road was made. He states that the name implies the base of a column and suggests that it was something more than a chance boulder. It should be stressed that his interest was the Dean Road, a road which was claimed to be Roman by many historians before and after his book. Trotter himself was careful not to conclude that it was Roman, whilst Bridgewater[2] in 1968 states that its construction is not typically Roman and the dating must be left open. The importance of this digression is to point out that there is an alleged Roman Road with plenty of conjecture and confusion viz: Waters[3] records in 1951 'the poachers melted their bullets through the hole in the old Pattern Stone close to Drummer Boy's Grave besides the paved Roman Road . . .' Baty,[4] 1952, writes 'the Drummer Boy Stone may have served as a cresset for they were not always on a height. The name, even after so many centuries, is probably the clue – if only we could interpret it.' The sense in which cresset is used here is to suggest that the hollows held oil or fat to give light either for navigational or devotional purposes.

Hence there is plenty of confusion between the two stones and their purpose. It could be asked whether the Pattern Stone ever really existed in its Ordnance Survey position and whether it was an alternative name for the Drummer Boy Stone in view of the obvious metallurgical use of the latter?

Cave,[5] 1972 suggested that the Drummer Boy Stone must really be associated with the primitive methods of the bloomsmithy era. In 1975 members of the Historical Metallurgy Group (as it then was) visited the site and a specimen of the deposit was taken for analysis.

Description

The stone is one of several natural, sparsely occurring, boulders in the valley. They and the bedrock are composed of a quartz conglomerate from the Old Red Sandstones of Devonian Age. The quartz pebbles show as white spots on the photos (Figures 1 & 2).

The Drummer Boy Stone is roughly rhomboidal in outline, 1.5 m by 1 m. Some 25 cm of rock are above ground level and some 40 cm below it. The upper surface of the stone is rough and sloping and has two hollows of about 20 cm diameter fashioned in it. They are about 8 cm deep but irregularly bounded. One of these hollows contains the deposit referred to. Close by is a further smaller stone with a hollow on its top.

Probing the surrounding ground did not reveal any further buried boulders. Pieces of slag are common in molehills and were retrieved from the soil alongside the stone. Their appearance would suggest that Trotter's 'pieces of clinker' were a similar material.

Metallographic Examination

This stone contains at least two well-formed spherical hollows, one of which is filled with a highly magnetic substance. A piece was chipped off the edge of this deposit and examined under the microscope. It was friable and is porous, but the structure consists of slag and particles of oxide which bear no relationship to either bloomery iron or cast iron. It is therefore a smithing slag and parts of it look exactly like the hammer scales shown in Figure XXVI, page 254 of the book 'Metallurgy in Archaeology.'[6]

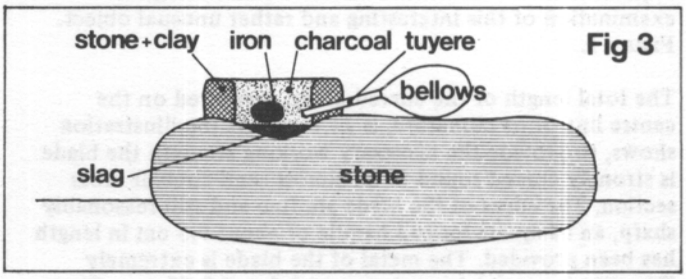


Fig 3

This is clearly an iron smithing product. It consists of particles of magnetite and wustite embedded in a fayalite-type ($2FeO.SiO_2$) slag formed by a mixture of scale, fuel ash and slag which has resulted from the heating of wrought iron for hot working. It is probable that the stone formed the base of a small hearth made of clay and stones and blown with the aid of a blast from a tuyere, as shown in the sketch (Figure 3). The re-heated iron would tend to shed the scale formed by high temperature oxidation, and this would be mixed with the other debris of the process, mostly fuel ash. There is no sign of coal ash, shale etc, and we would think that this is the product of smithing wrought iron with charcoal. The only way of dating the operation would be by thermoluminescence dating of the stone in contact with the slag.

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A Bronze Strigil from Greece examined

H H Coghlan ©

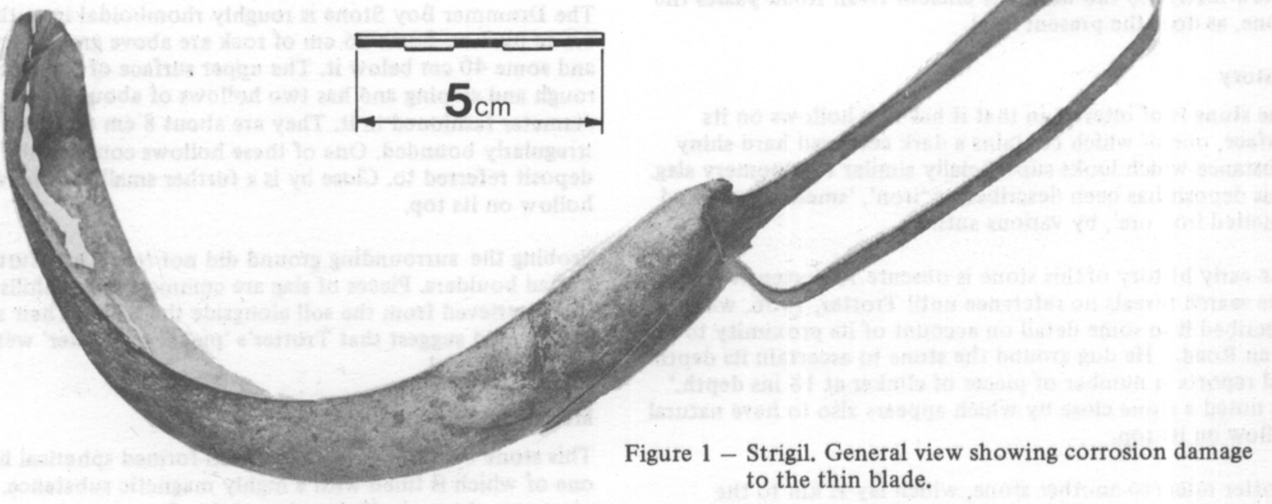


Figure 1 – Strigil. General view showing corrosion damage to the thin blade.

This strigil, or skin scraper, was obtained in Greece by the late H.J.E. Peake. The Newbury Museum records give the provinance as Athens, and suggest a date of between 500 and 300 BC. Since it was surplus to the museum requirements it was decided to make a metallurgical examination of this interesting and rather unusual object. Figure 1.

The total length of the curved blade, measured on the centre line of its curvature, is 21.8 cm. As the illustration shows, to provide the necessary working strength the blade is strongly curved round to an almost semi-circular cross section. The edges of the blade are fine and still reasonably sharp, an adequate looped handle of about 9.5 cm in length has been provided. The metal of the blade is extremely thin, varying in thickness between 0.5 and 0.75 mm. The most substantial metal is found in the handle where a maximum thickness of 2.5 mm is attained. The weight of the strigil, as received, is 65 grammes. In the portion furthest from the handle the thin metal of the blade has, in places, been much attacked by corrosion. Here, cracking has occurred and relatively large areas of metal have completely corroded away. In the rest of the blade and the handle visual examination suggests that the metal is in fair condition, and not seriously attacked by corrosion. The patination, originally of a dark green colour, is now somewhat rough. Any original polish which there may have been is lost.

There is no doubt that the strigil is a wrought product, it was not made as a casting, but fabricated from one piece of sheet metal. The curved blade was probably shaped by raising or sinking, the handle forged to shape and finally bent round and secured to the back of the blade by an arrow-shaped lap and soft solder. It was found that, over most of the length of the lap the soldered joint had failed. The whole implement is a skilful example of forged work. We have the very thin and uniform metal of the blade then the considerably thicker metal of the handle, and finally, the arrow-shaped lap had to be shaped to fit the contour of the back of the blade. In particular, the transition from the curved blade to the flat metal of the handle has been most skilfully executed, this zone between blade and handle must have been a difficult piece of forging, but it has been carried out in a very neat and regular manner.

For metallographic examination, sections were taken through the blade and through the soldered joint between the blade and the lap of the handle. Sections were also taken from the region where the blade merges into the handle, and from various parts of the handle. Analysis most kindly supplied by Mrs A.M. Sumner showed the material to be a tin bronze with the following impurities, expressed as percentage figures:

Copper	Major quantity	Tin	Present
Zinc	0.001/0.005	Lead	~0.1
Iron	0.1/0.5	Nickel	~0.05
Manganese	<0.001	Aluminium	<0.001
Silver	0.001/0.005	Antimony	0.05/0.1
Bismuth	<0.001	Arsenic	0.1/0.5
Silicon	~0.001		

From the above figures it will be noted that the bronze is of considerable purity, although iron in the composition in the range 0.1–0.5 percent is higher than we usually find in prehistoric bronze of good quality. This may have occasioned some measure of grain refinement.

Examination of the metal of the blade (an α bronze), in the unetched state showed it to be clean, and substantially free from porosity and inclusions. $\alpha\delta$ eutectoid was not observed in any of the sections but the eutectoid, if originally present, could have been absorbed in the course of the probably numerous annealing and working cycles. At one of the working edges of the blade cracking, no doubt due to cold hammering, has occurred. Here, penetrative corrosion has followed the cracks. In order to examine the ductility of the bronze, free cold bend tests through 180° were carried out on material taken from the thin blade (thickness 0.75mm), and also upon slightly thicker material (thickness 1mm), from the handle. In each case the bronze was found to be ductile, and withstood the bend tests without cracking or other visible defects.

Upon etching the various sections structures of equiaxed twinned crystals of extremely small grain size were revealed. (Figure 2). No evidence of coring could be seen, and the metal has been homogenised. In view of the small grain size observed, it is probable that the metal was subjected to severe cold working prior to annealing, and that annealing was carried out at low temperature. As we have mentioned, most of the metal was substantially free from inclusions.

Figure 2 – Small equiaxed twinned crystals which are typical of the material as a whole. x 200.

However, in one section through the handle, non-metallic inclusions plastically elongated in the direction of forging were seen. (Figure 3). Mr R.F. Hills kindly carried out a hardness survey and plotted the results for a complete cross section through the blade. He found that the hardness was reasonably constant over most of the length. Here, the average from eleven readings was 151 KV, maximum and minimum figures being 180 and 134 HV. At the two cutting, or rather scraping edges, the hardness somewhat increased. At one edge the average from three readings is 163 HV. (maximum 165). At the other edge the average from five readings is 181 HV (maximum 191). These figures show that a measure of general hardening has been applied to the blade.

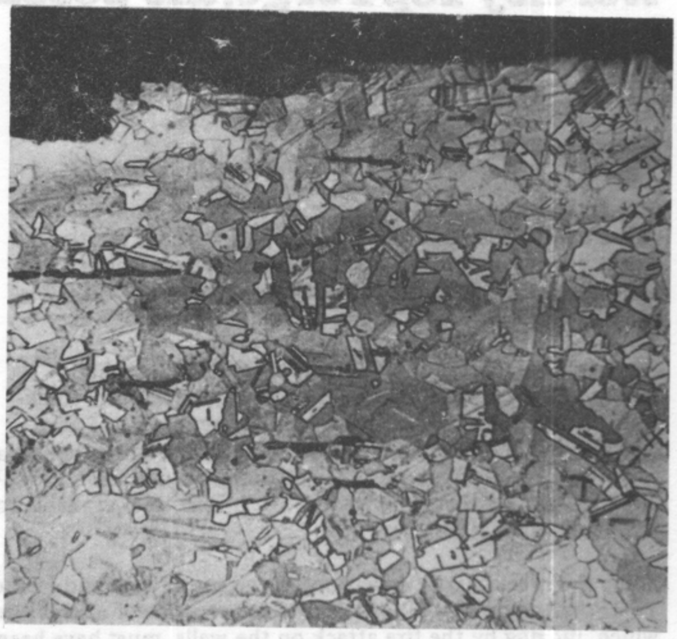


Figure 3 – Showing some non-metallic inclusions plastically elongated as a result of forging. x 200.

Mr Hills mentions that, compared with the centre region it is evident that slip lines are present in the cutting-edge, and this ties up with the increased hardness there. Apart from the probable desire to harden the scraping edges the smith probably knew that some hardening over the length of the blade would be necessary in order that a blade made of such very thin bronze could maintain its shape during use.

A satisfactory job had not been made of the soldered joint between the back of the blade and the handle. At only one restricted place was the joint holding, and even here, the joint failed during cutting out of the section. The metal has not been adequately 'wetted' by the solder, and if a flux was used it cannot have been an efficient one. Throughout the joint very little solder could be detected, and it is probable that most of it had corroded away. As we have mentioned, corrosion attack upon the thin metal of the blade has been severe, but in the sections taken from the more substantial metal of the handle it was found that corrosion attack has been slight, and the metal remains in good condition. Perhaps the most interesting feature of this strigil is the way it has been fabricated from one piece of metal of varying thickness, very thin in the curved blade, but of appreciable thickness in the handle. The total length of the single piece of bronze from which the strigil has been made is approximately 50 cm. This thin strip may have been forged down from an 'ingot'. The preparation of the strip alone would call for skill. Finally, an excellent job was made of the finishing operations. The smith was clearly well skilled in the art of sheet metal working.

Acknowledgements

It is a pleasure to thank Dr George Parker for the photograph of the strigil, Figure 1. Mrs A.M.Sumner for the analysis, and Mr R.F. Hills for the hardness plot, etc.

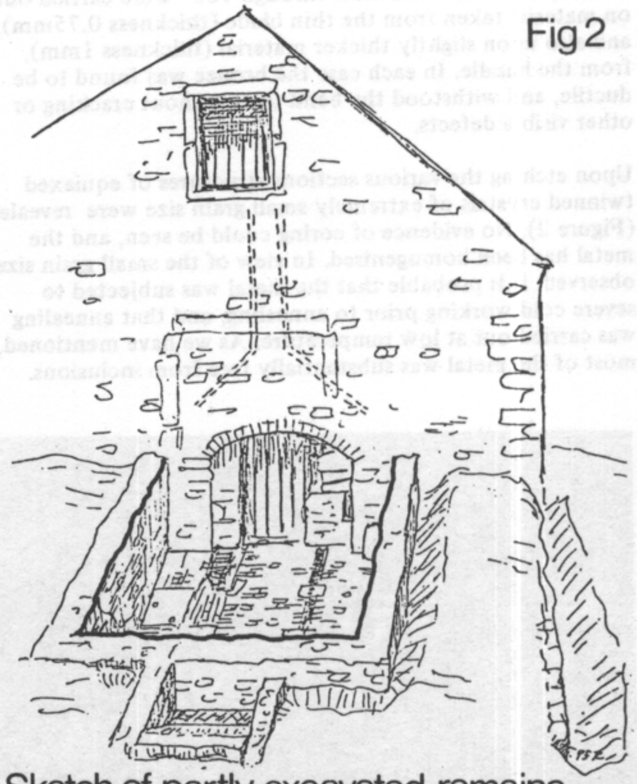
Wortley Top Forge, the possibility of early steel production

K C Barraclough ©

It has always been inferred that the period when Wortley Forge was in the hands of the Cockshutts, from about 1765 until the end of the century, various experimental activities were carried out in addition to the manufacture of iron. Schubert[1] points out that the principal production centre for shear steel was near Newcastle upon Tyne but that another centre was Wortley in Yorkshire where 'John Cockshutt took up this manufacture around the middle of the century, but the steel he made was not as such a high repute as Crowley's'. This information seems to have come from Lewis[2] and presupposes there was a source of blister steel available to him for forging at Wortley.

Some few weeks ago, excavations at the south west end of the Top Forge complex at Wortley revealed remains of a structure which, judging by the fire attack on the walls, must have been a furnace. The walls were not keyed into the building now known as 'The Foundry' and, therefore are taken to be later. It has been assumed the Foundry could well have been part of the 1713 additions to the Forge although there is no firm evidence for this early date. The inner, fire-attacked walls seem to be surrounded by outer walls (not yet excavated) running somewhat at a divergent angle whilst the end wall carries what can best be described as a chute, in stonework, as are the walls. Some five to six feet below the present ground level there is a central floor, mainly in brick, but with six stone slabs let into it, the whole arrangement being shown in Figure 1. The only other feature remaining of interest is the ghost pattern of a chimney on the outer end wall of the Foundry, placed along the centre line of the furnace structure, as can be seen from Figure 2.

Fig2



Sketch of partly excavated remains

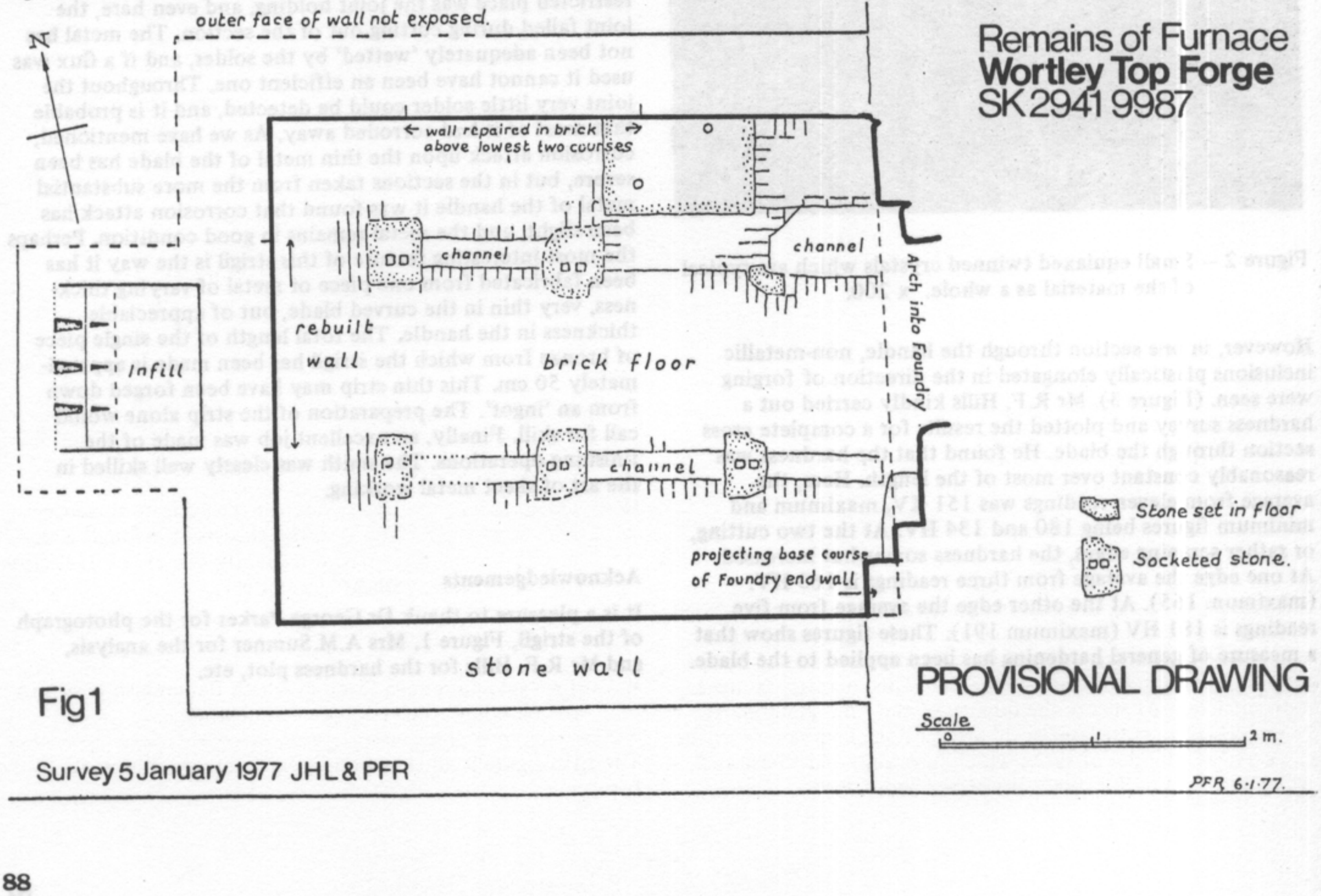


Fig1

Survey 5 January 1977 JHL & PFR

This rather puzzling set of remains brings to mind the drawings published by Hassenfratz which are reproduced as Figure 3.[3] It appears the original drawings come from Jars; these are reproduced as Figure 4, and the accompanying text is given in translation in the Appendix.[4]

From this information it should be noted that Jars indicates that the small experimental furnace which he shows can also serve as a model for the single chest furnaces which are used in Sheffield and it does therefore seem not unreasonable to suggest that here at Wortley we have the remains of one of the earliest South Yorkshire cementation furnaces. This suggestion is given a little further credibility by the discovery of charcoal, coal and fire reddened sandstone chips as well as slagged pieces of brick in the lowest layers of debris removed above the brick floor and the appearance of the bricks themselves which would not be unlikely in a late eighteenth century context.

The most interesting feature, the chute, has been blocked off later by a stone wall infilling, quite clearly visible by the non-conformity of the stonework joints. If this is indeed, a cementation furnace, this method of firing (which is clearly described by Jars, as in the marked paragraph in the Appendix) renders it somewhat unique.

The structure, however, seems to vary from that shown by Jars in that the chimney is placed at the end, rather than at the side. This could produce a more directional flame; on the other hand, if indeed the furnace operated as we have surmised, this could explain the fire reddening on one wall and the flame attack on the brick infilling on the opposite wall by a mushrooming effect of the flame mid-way along the furnace length.

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2 J Lewis: 'History of the Iron & Steel Trade' (Manuscript in the Cardiff Museum) Vol. iv, p.225.

3 F Hassenfratz: 'Sidérotechnie' (Paris 1812), Vol. iv, Plate 61, and descriptive text, pp. 260–261.

4. G Jars: 'Voyages Métallurgiques' (Lyons, 1774), Vol. 1, Plate 8 and descriptive text, pp. 361–365.

ACKNOWLEDGMENT

Figures 1 and 2 are reproduced by kind permission of Mr J H Little, Archaeologist to the South Yorkshire County Council.

APPENDIX – G JARS: 'VOYAGES METALLURGIQUES' (Translation by K C B)

Plate 8 (Figure 4)

This plate represents the design of a trial furnace for the conversion of iron into steel.

The furnace is small and of a low construction cost but it must be made with the greatest precision. It permits the cementation at one time from three to four hundredweights of iron, depending on the thickness of the bar. This quantity is more than sufficient to ensure the quality of the iron which must be employed to start large scale production. This same furnace can serve as a model of those which have only one chest and which are used in Sheffield. It is described below.

The first figure is a plan of the furnace at the level of the ashpit.

A The ashpit.

B Body of brick masonry to resist the furnace heat.

C Two blocks of ordinary masonry surrounding and supporting the furnace.

The second figure is a section along the line CD.

A The ashpit.

B One of the arches supporting the chest.

C The chest in which the iron is cemented.

D Flame passages.

E Interior of the furnace vault.

F Entry passage to chimney.

G Chimney.

H The two blocks of masonry supporting the furnace.

The third figure is the plan at the upper level.

A The two blocks of masonry.

B The firebox where the coal is fed to heat the furnace.

C The chest made in bricks, 8″ long x 4″ wide; in it the iron is placed for conversion to steel.

D Several small flame passages so arranged that they surround the chest to give equal heating in all parts.

The fourth figure is a section along the line AB of the plan.

A The firebox.

B Opening through which ashes are removed.

C. Is a pile of sand covered with clay so as to lose as little heat as possible.

D. The five arches supporting the chest.

E The chest where the iron is cemented.

F Flame passages.

G An opening closed during working but opened when required to withdraw a bar of iron to learn whether it is sufficiently cemented.

H Opening into the upper vault of the furnace through which enters the iron into the chest and through which it is withdrawn, when it is sufficiently cemented. It is closed during working with bricks and clay.

I The main chimney.

K Two side chimneys through which flames also pass into the chimney to give more even heating.

The fifth figure is an elevation in perspective of the same furnace.

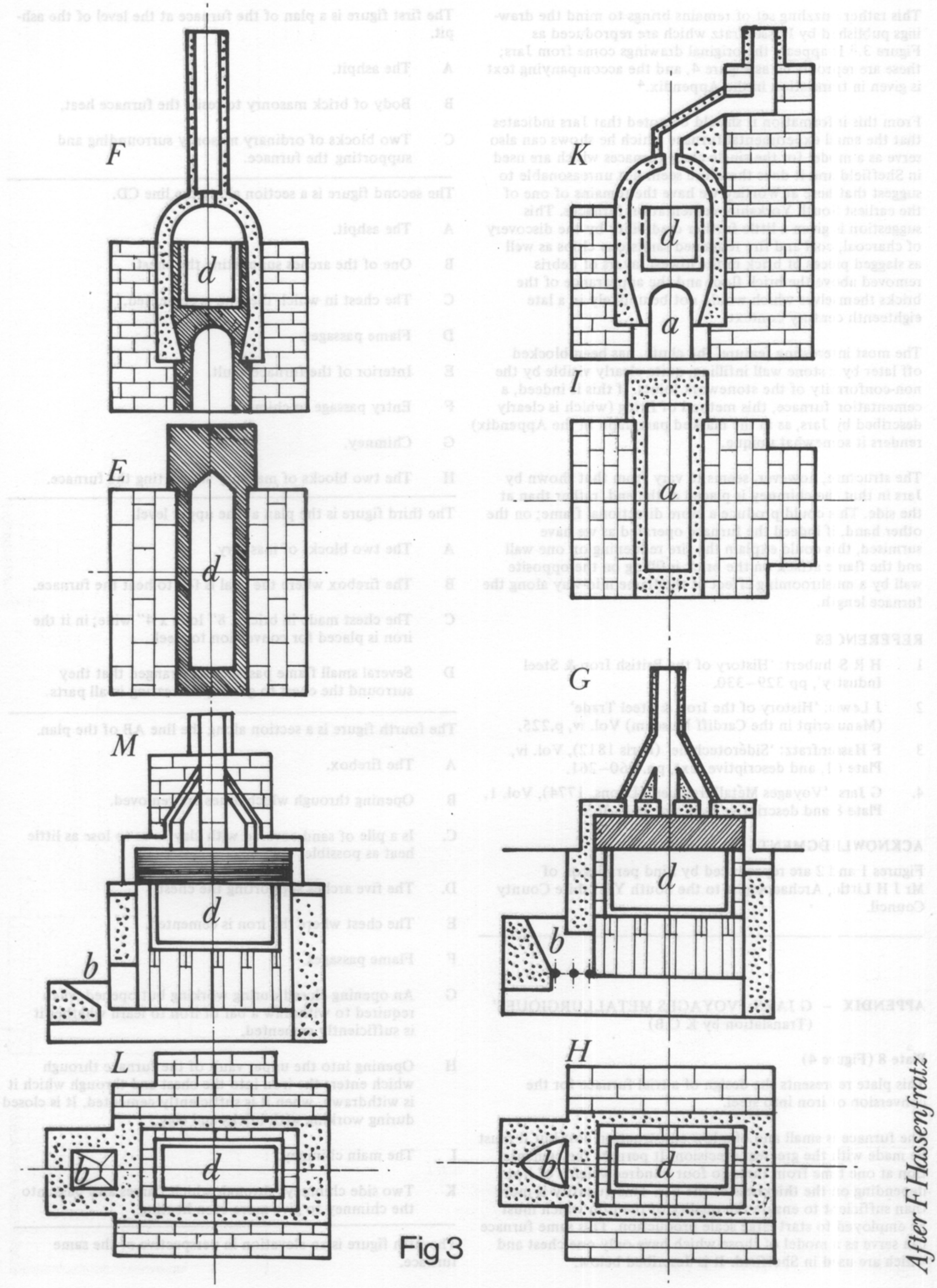

Fig 3

After F Hassenfratz

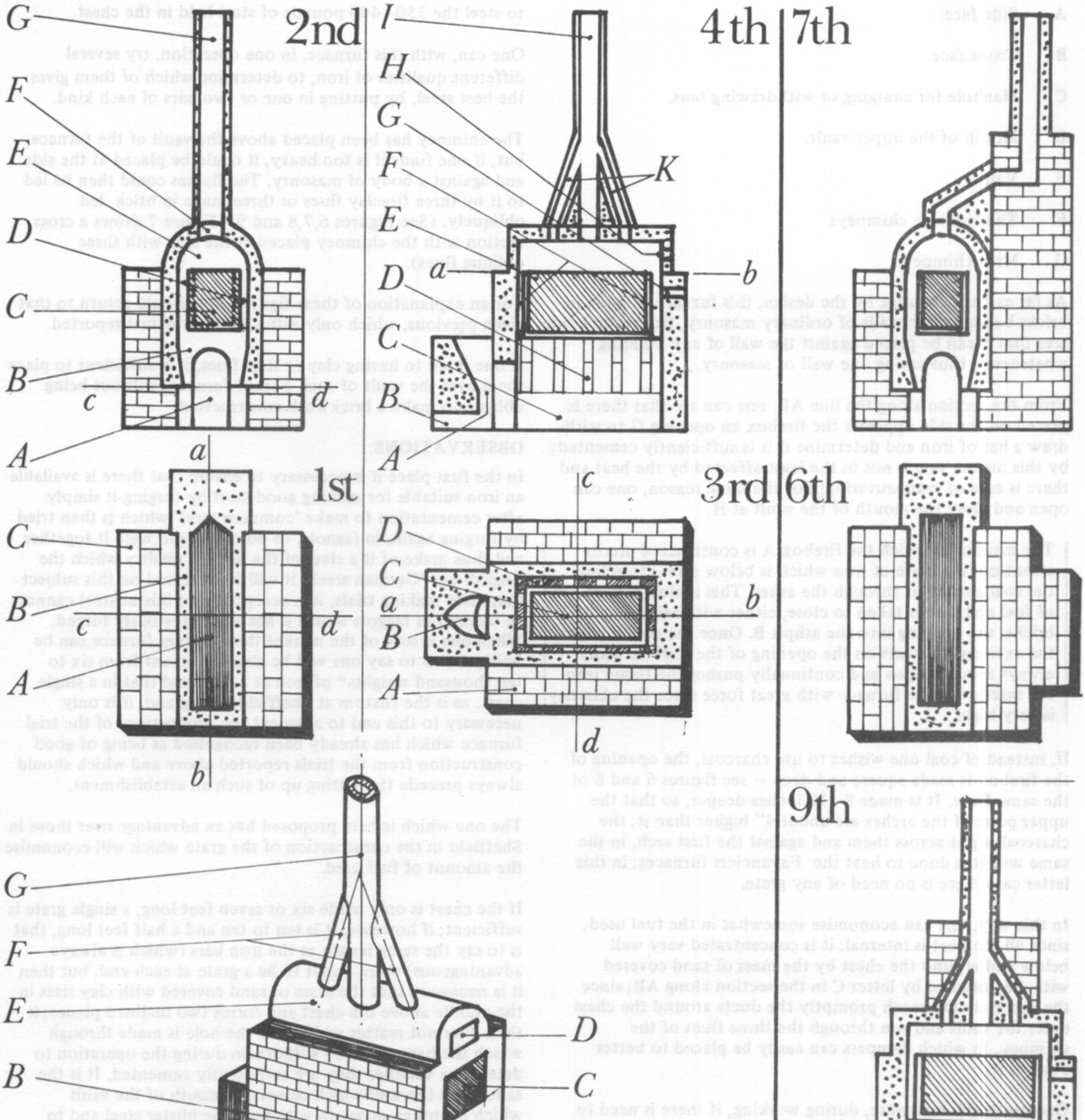

Fig 4 *After G. Jars*

A	Side face
B	Front face
C	Manhole for charging or withdrawing bars.
D	Mouth of the upper vault.
E	Vault.
F	The two side chimneys
G	Main chimney

As far as one can judge by the design, this furnace is made in bricks between two walls of ordinary masonry, from which one sees that it can be placed against the wall of any building whatsoever, thus saving one wall of masonry.

From the section along the line AB, one can see that there is placed on the side opposite the firebox an opening G to withdraw a bar of iron and determine if it is sufficiently cemented; by this means, one is not in the least affected by the heat and there is ease of manoeuvering; For the same reason, one can open and close the mouth of the vault at H.

> The manner in which the firebox A is constructed merits attention; the grate of iron which is below serves to retain the coal and to let through the ashes. This is always kept full of fuel and care is taken to close, either with ashes or with bricks, the opening into the ashpit B. Once the coal is alight, the external air beats on the opening of the firebox which always remains open and continually pushes the flame into the interior of the furnace with great force since the chimney is very high.

If, instead of coal one wishes to use charcoal, the opening of the firebox is made square and deep – see figures 6 and 8 of the same Plate. It is made 8–10 inches deeper, so that the upper parts of the arches are about 4" higher than it; the charcoal is put across them and against the first arch, in the same way it is done to heat the Fayanciers furnaces; in this latter case there is no need of any grate.

In this way, one can economise somewhat in the fuel used, since all the heat is internal; it is concentrated very well below and around the chest by the mass of sand covered with clay marked by letter C in the section along AB; since the flame should reach promptly the ducts around the chest enter the vault and run through the three flues of the chimney, in which dampers can easily be placed to better control it.

One can easily recognise, during working, if there is need to use these dampers by means of spy hole built in the small temporary wall constructed to close the opening H.

Despite what will be said below, that the English make their chests in sandstone, they can be made in brick when they are of good quality. The chest of the furnace proposed here can be made of bricks 8" long and 4" wide x 2" thick; it has been shown in the two sections and in the upper plan how they are assembled to be carried by the arches and to make the constructions solid.

We shall not enter there into detail of their management; we go back to that which is reported in the process described in the memoirs; we will limit ourselves to saying that in a similar furnace, constructed in one of the suburbs of Paris, it has been observed that, when firing with charcoal, it is ncessary to have continuous operation during 45–50 hours to convert to steel the 350–400 pounds of steel held in the chest.

One can, with this furnace, in one operation, try several different qualities of iron, to determine which of them gives the best steel, by putting in one or two bars of each kind.

The chimney has been placed above the vault of the furnace; but, if one finds it is too heavy, it could be placed at the side and against a body of masonry. The flames could then be led to it by three fireclay flues or three made in brick, led obliquely. (See Figures 6,7,8 and 9) (Figure 7 shows a cross section with the chimney placed at the side with three oblique flues).

For an explanation of these figures, one should return to that given previous, which only differ in the way just reported.

If one is led to having clay or iron flues, it is sufficient to place them over the vault of such a small furnace, without being obliged to make a brickwork construction.

OBSERVATIONS:

In the first place it is necessary to ensure that there is available an iron suitable for making good steel by forging it simply after cementation to make 'common steel' which is then tried by forging again, in faggots, to double it and weld it together and thus make of it a steel of the highest quality which the English call 'German steel'; it will be observed on this subject that after making trials, it is accepted that blister steel cannot be worked in faggots unless it has been previously forged. When one is sure of the market then a larger furnace can be built, that is to say one will be able to cement from six to ten thousand weights* of iron at a time and that in a single chest, as is the custom at Sheffield in England; it is only necessary to this end to augment the proportions of the trial furnace which has already been recognised as being of good construction from the trials reported above and which should always precede the setting up of such an establishment.

The one which is here proposed has an advantage over those in Sheffield in the construction of the grate which will economise the amount of fuel used.

If the chest is only made six or seven feet long, a single grate is sufficient; if however, it is ten to ten and a half feet long, that is to say the same length as the iron bars (which is always advantageous) there ought to be a grate at each end, but then it is necessary that the mass of sand covered with clay rises in the middle above the chest and forms two inclined planes; it then does not matter which side the hole is made through which the bars are to be withdrawn during the operation to determine whether they are sufficiently cemented. It is the same with the wall which closes the mouth of the vault which is broken down to withdraw the blister steel and to introduce the new iron into the chest.

It is not necessary to consider in such a furnace the construction of the chimney over the vault but at the side; it is believed that it is proposed to make four openings in the vault so as to equalise the circulation of the flame, each of which will have an oblique flue to carry the flame into the chimney.

For the rest, one feels that the quantity of iron which is required to be cemented will increase but it will take some time to come about. For example, comparing what is happening in Sheffield, it will need five times twenty four hours with a furnace whose chest is ten feet long, which is equal to one from one of the larger furnaces. One cannot however be precise in this respect, since it depends principally on the fuel employed, the proportions observed in the furnace, the size of the chest and finally the quality of the iron.

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*three to five tons.

Work in progress

EXCAVATIONS

Polish Metallographical Research of Early Bulgarian Iron Artifacts found at Styrmen. During field work carried out at the medieval fortress of Styrmen, Bulgaria, there were observed iron slag accumulations in some of the areas excavated. These are believed to be due to smelting activity. Unfortunately, no firm evidence of furnaces, hearths, etc could be ascertained. According to the chemical composition of the slag (low Fe0 content, high silica, etc) another explanation is possible, ie that these are smithing cinders.

Thanks to Prof Z Glowacki and Mrs H Przygodska (Institute of Technology, Poznan) a considerable number of the 127 iron objects dating from the 8–11th centuries have been analysed. A small number of specimens (16) are of a later medieval date. The metallographical examination consisted of microscopical observations and microhardness tests. The series includes mostly tools and agricultural implements (70 specimens, 25 of which are knives); weapons and missiles in the form of arrowheads are represented by 37 objects; to the rest belong fittings and various fragments.

An extended commentary of results was compiled by Mgr. H Mamzer (Zaklad Archaeologii Wielkopolski PAN, Poznan). The main part are of artisan's tools manufactured by progressive techniques based on the iron-to-steel welding. It is noteworthy that construction systems were mostly limited to simple faggoting of wrought iron and carbon steel strips, while more sophisticated methods as steel inlays and the so-called sandwich-schemes were rarely applied. Welding-on of steel edges was not, in fact, practised. Other techniques (carburizing of edges or surfaces) are scarce. Nearly 50% of quench-hardenable artifacts were heat treated.

There are some comparisons to be made with the technology of iron artifacts of Great Moravian origin, which are partly of the same date. The question is discussed whether and to what extent the welding techniques are to be derived from traditions common in workshops of former Roman provinces along the Danube. Let us add that in the case of early Bulgarian blacksmith's craft the heritage of the steppe technologies should be taken into account as well. This suggestion may explain the existing differences between the Great Moravian and Balkan products.

The results of the above research – which are useful in spanning the gap in our present knowledge – are to be published as supplements to a monograph devoted to the Styrmen excavation.

Interpretation of Sussex Roman Iron Smelting Plants. At the present stage of research on the Roman Iron industry of the Weald of Sussex, England, an attempt has recently been made by H Cleere (Council for British Archaeology) to evaluate all available data and to state the role of the Classis Britannica in an area of 300-500 sq km over a century. The following main subjects were studied:
1 Regional production figures, calculated from the remaining slag heaps and slag-metalled roads, related to the production of individual sites and furnaces. 2 Consumption of raw materials (ore, timber), related to sources of supply, and the effect on the landscape (mining, deforestation).
3 Manning requirement, used to produce demographical data.

There is no doubt that this will be an important contribution to the industrial and economical history of Europe, which may invite comparisons and a new examination of Europe's other ancient iron smelting regions. A paper on the operating parameters for the Roman ironwork of South England is under preparation.

After H Cleere, London

Smelting Furnaces of the Avaric Period in Hungary: During 1975 there were excavated two iron smelting furnaces near Torjanpuzzta, Gyor-Sopron district, western Hungary. In front of their open hearths (depth about 30 cms) were flat operating pits where molten slag protruded from the hearth area. Remains of the original shaft superstructure reached the height of about 10 cms. The lower furnace diameter measured ca. 30 cms. Fragments of clay tuyeres in shape of bricks were found. The pottery indicates a date of the 7th century AD corresponding to the Avaric settlement in Pannonia. Archaeomagnetic tests in order to confirm the dating were undertaken; the evaluation is still in progress.

J Gomori, Sopron, (After CPSA)

New working groups at the Swedish Berghistoriska Utskott Jernkontoret. One group will go into the problems of iron production of the Middle Ages (ca. 1000–1500 AD). A systematical research on various museum collections is planned in order to secure a fund of material for future analyses as well as for the registration of the relevant written sources. The second group will direct the activity on the dating of Sweden's most ancient iron mines and the use of different sorts of ores in individual periods. A bibliographical index is also being prepared for publication. It will cover the European literary production in the field of the early iron industry.

A recent excavation by I Serning revealed two shaft furnaces with slag-pits near Mille Torn, Stang parish, Gotland. ^{14}C dates indicate an unexpectedly early date of 200 BC. Another furnace has been excavated by L Thalin in Vestergotland. It was equipped with a number of clay tuyere nozzles but the feature was badly disturbed. Dating indications are not yet available.

The authors, A Hyenstand, W Holmqvist, K Calissentlorff and I Serning have prepared for publication a book entitled 'Prehistoric Iron in Sweden'.

After I Serning, Hallsjon (CPSA)

Traces of Roman Iron Making at Szombathely, Hungary. Excavations in the urban area of Szombathely, ancient Savaria, revealed iron slag dumps in the Roman settlement layers. According to the estimation of Mrs M Medgyes, director of the excavations, this waste reminds her of tapped slag from reduction furnaces.

After J Gomori, Sopron, After CPSA

Roman Period Settlement with Iron Working at Bystrany near Teplice, NW Bohemia. In the course of rescue operations in the inundation of the Bystrice brook there were excavated, in 1975, fourteen features relating to the 1st-2nd centuries AD. Besides two sunken-floored huts, attention should be paid to two reheating hearths for iron blooms. They were flat and longitudinal in plan (dimensions 120 x 50 cms, depth about 40 cms), lined with burnt clay and filled with charcoal and iron slag lumps.

J Waldhauser, Teplice, (After CPSA)

A newly discovered Iron Smelting District East of Warsaw, Poland. Field reconnaissances organised in 1967/74 by the author of the present abstract brought to light a large protohistoric smelting area in the Mazowsze, plain of Bonie, measuring ca. 300 sq km between Warsaw, Leszno, and Grodzisk Mazowiecki. About 70 iron-slag-bearing sites have been registered up to the present day. The most important among them, Milamowek-Falecin, Brwinow, Biskupice, Parzniew, Pruszkow, Pecice, Kanie, represent bloomery plants combined with extended industrial settlements. This industry dates preliminarily from the Late La Tène and the entire Roman period, with a concentration in the initial phase (about BC/AD).

Excavation operations started in 1974; about 250 furnaces of the slag-pit type were uncovered, varying in shape and size. They produced heavy slag blocks weighing from about 20-30 kg up to 250 kg. Many slag pits were equipped with channels pointing from the bottom of the hearths to the surface. (Their real purpose must be studied in detail; not being parts of a normal blast, they possibly served for combustion of wood-filling of the pit before receiving molten slag from upper levels. Editorial note). In 1975 a cupola-shaped kiln of 250 to 100 cms, situated in a large building, would be investigated during excavations at Milanowek-Falecin. Layers of limestone were observed in the bottom.

Further investigations supported by geophysical methods are planned in this important area by the Muzeum Starozytnego Hutnictwa Mazowieckiego w Pruszkowie.

S Woyda, Pruszkow

METALLOGRAPHY

Near East Iron Objects examined at the University of Pennsylvania Laboratory. In 1975, the undersigned team was concerned with the metallurgical structure and elemental chemical analyses of iron objects from Nimrud, Toprakkale, Hasanlu and Al Mina, Syria which will be published in **Levant** for 1976 and 1977. The Al Mina tools (ca. 400 BC) reveal that the smith knew how to develop properties appropriate to the function of the tools. The chisel was made by sacrificing some of its hardness for durability through insulating its edge before quenching, while the adze is made of two layers of iron – one carburized and the other uncarburized – with the carburized layer being the working surface.

The Toprakkale spearhead (Lake Van, eastern Turkey) contains a surviving core of metal, the edges of which show uniform carburization. The spearhead itself must have been heavily carburized on the surface in order to produce the slight carburization in the surviving metal. A collection from objects from Nimrud, northern Iraq – all oxidized with two notable exceptions – show the ghost relics of carburizing treatments. The curious objects called 'ingots' (ca. 700 BC) are sound metal and have carburized and quenched edges. The fact that they were subjected to sophisticated treatment casts doubt on their identification as ingots.

Vincent C Pigott, Jr is studying with the team the Hansanlu irons (northwestern Iran), and plans have been made to examine tools from Egyptian Thebes, 'ingots' from Khorsabad,and Susa, and iron objects from several Israeli sites (such as Taanech, etc) in 1976.

R Maddin – J D Muhly –
Tamara S Wheeler,
Philadelphia

Further Investigations of Assyrian Irons from Khorsabad. The team of Mrs T S Wheeler and R Maddin, University of Pennsylvania, investigated two pointed iron bars from the Collection of the Oriental Institute Museum at Chicago. Their preliminary report entitled 'Metallurgical study of two iron objects from Khorsabad' will be the basis of a future publication. Another bar from the same site and from the same collection has been examined by R Pleiner at the Prague metallographical laboratory of the Archaeological Institute. This artifact will also serve as a contribution to the discussion on the real purpose of these objects. The latter report, which is also prepared for publication, will be completed with the analyses of two working tools from Khorsabad. All specimens mentioned above date from the late 8th century BC.

Metallographical Study of La Tène Period Iron Swords has been started in the Prague laboratory of the Archaeological Institute of the Czechoslovak Academy of Sciences. Three swords from the well known inhumation cemetery at Jenisuv Ujezd and two other pieces from the cemetery at Makotrasy (Bohemia) have been investigated. Burial mound No. 8 at Zemplin (Slovakia) yielded a well preserved sword with a stamped Roman mark. A comparative study deals with a sword fragment from a La Tène site.

R Pleiner, Prague (CPSA)

Conferences

Sitzung des Geschichtsausschusses des Vereines der Deutschen Eisenhuttenleute, Eisenhuttenhaus, Dusseldorf. Held on March 4, 1976. The following papers were concerned with early iron manufacturing: C Bohne: Gedanken zum Aufkommen des Norischen Stahles. Among others the problem of small bi-pointed bars as semiproducts of the Noricum smelting centre was mentioned. Prof. Schaaber completed the above contribution with some remarks on metallographical investigations of artifacts having their origin in that area: traces of graphite in some of them show that molten carburized drops were formed during the work with the very hard steels. F K Naumann – D Horstmann: reported on a metallographical examination of medieval artifacts from Sindelfingen and Esslingen-St. Dionysius, near Stuttgart.

Ancient Production of Iron in the Scientific Programme of the IXth Congress of the VISPP, Nice – Parc Valrose 13th–18th September, 1976. At the occasion of the top meeting of archaeologists from all over the world numerous contributions were enlisted dealing with the problems of the use of iron, its production or working in ancient civilizations. Only a part of them was actually read due to the absence of the relevant participants. Therefore it may be useful to quote the items according to the volume entitled 'Résumés des communications (Nice 1976)'. Section VIII Age du fer, subsection VIII–1 L'introduction du fer et le premier Age du fer: A Laszlo (Roumania): Les débuts de la métallurgie du fer dans l'espace Carpatho-Danubien, p. 509 (finds of HA–HB dates in Roumania); J Gomez (France): La premiere métallurgie de fer dans le Centre Ouest de la France, p. 511 (iron fragment in the hoard from Venet, HB$_3$); J P Mohen: (France): Bronze et fer en France au premier Age du fer, p. 512 (general remarks); B Scott (Northern Ireland): The study of early iron working in Ireland – Problems of theory and method, p. 532–533. Subsection VIII–2 Les Celtes et l'époque de la Tène: I Glodariu (Roumania): La metallurgie du fer en Dacie, p. 561; R Spehr (GDR): Zum Auftreten eiserner Ackerbaugeraten bei den Kelto-Iberern, Kelten und Dakern, pp. 568–570 (diffusion of iron plough-shares from Palestine to Central Europe). Subsection VIII–4 Les civilisations de fer dans le monde: J V Martins (Portugal): L'age du fer dans le Nord-Est de l'Angola, P. 600 (beginnings in the 11th century AD, furnaces, bloomeries). Section IX Periodes des Grandes Migrations, subsection IX–3 Les Vikings: J Selirand (USSR): Zur Frage der nordeuropaischen Waffenschmiedearbeit in der Wikingerzeit, p. 633 (role of the pattern-welded lance-head in the Baltic area). Furthermore the printed programme and posters of individual sections list the following papers, the greater part of which were not read: R Abramichvili (USSR); L'Age de Fer; M Kantcher (Bulgaria): L'introduction du fer; V Trbuhovic (Yugoslavia): De nouveau sur les plus anciens objets de fer sur le moyen Danube; M Cicinova (Bulgaria): La Thrace a l'Age du fer ancien (IX^e–VI^e siecles); H F Cleere (GB): The iron industry of the North-Western Roman provinces; H Loofs (Australia): Les débuts de la métallurgie du fer dans la péninsule indochinoise; J Alexander (UK): A comparison of the spread of iron-using in Africa and Europe.

R Pleiner, Prague.

II^e Congres International de Thracologie, Bucarest, 4th-10th September, 1976. The programme of the congress published as 'Résumés des rapports et communications (Bucarest 1976)' gives the list of the following papers dealing with early iron industry in the world of Thracians and Dacians: I Ferenczi (Roumania): Die naturlichen Voraussetzungen der Eisenmetallurgie in dem Gebirge südlich von Orastie, p.57-58; I Glodariu (Roumania): Les ateliers metallurgiques de la Sarmisegetuz dace, p. 64 (about 2 tons of iron bars deposited in the ancient town; bloomeries outside the walls in the environs); V D Inkova (Bulgaria): Technologiya obrabotki zeleza vo Frakii pervogo tysyaculetia do nasej ery, p. 78 (Metallographical investigations of iron artifacts dated to the Hallstatt and the La Tène periods in the Thracian area); M Rusu (Roumania): Le centre métallurgique transylvain, pp. 120–122 (Greek, Celtic and Roman influence on the development of the Dacian iron industry).

R Pleiner, Prague.

XVIth Seminar Devoted to the History of Metallurgy organised by the National Technical Museum at Prague together with the Club of Friends of the NTM, 11th November 1976. The bulk of papers dealt with the later history of iron industry in Bohemia and Moravia. With prehistory was concerned the contribution read by R Pleiner: Sireni zeleza do Evropy (The Spread of iron into Europe).

R Pleiner, Prague.

Book reviews

Noel Barnard and Sato Tamotsu. Metallurgical Remains of Ancient China. Nichiosha, Tokyo, 1975. Format, A3. 343pp + xxxii. Frontispiece and 3 plates in colour, 55 figs. and 26 maps. Price $99.5

This is a truly ambitious and monumental work. Noel Barnard is well known for his contributions on this subject and has here been ably helped by his one-time research assistant and later research officer. The dedication to a master-printer is unusual but perhaps one that all of us who write books should remember. Tanaka Tadao unfortunately did not live to see the volume through the press and arrangements were made with the present firm with the active encouragement of of Tanaka's widow and family.

The book is trilingual. It consists of three main parts. The first is a monograph in English on the origins of bronze casting in China which is followed by a Japanese summary. The second part is a detailed table in Chinese of excavated sites on which metal has been found dating from Han or earlier times. The third part consists of a series of distribution maps with captions and some discussion in both English and Japanese. This is cross-referenced to the list of excavated sites in Chinese.

The survey of sites yielding metal artifacts takes in to account the greater part of controlled excavations from 1923 to 1949 and almost all that reported between 1954 and 1966 when publication ceased as a result of Red Guard activities. Although publication was resumed in 1971 it has not been possible to deal with such recent material in this book.

For the non-Chinese reader the section of greatest interest is that entitled "Origins of Bronze Casting in China". This section does not in fact limit itself to copper-base metals but includes subsections on the iron foundry and forge, and techniques and other metals (precious metals and decoration, for example).

As the title implies, it includes a discussion as to whether the origins of metallurgy in China were indigenous or diffused (this matter might have been more logically placed as a discussion leading to a conclusion at the end). Unlike Joseph Needham, Barnard and his colleague come well down on the side of indigenous metallurgy although they admit that, with very few exceptions, copper-base metallurgy is almost entirely restricted to bronze. There is little evidence for an evolutionary sequence developing from copper through Cu-As, Cu-As-Sn, Cu-Sn, etc as in other parts of the world; so the authors rest their case on the early, highly sophisticated, pottery industry. They seem to feel that signs of an earlier metallurgical tradition will be found in due course. At the moment the Early Shang (pre-Anyang, 1850–1650 BC) phase seems to show all the signs of a developed bronze age but with many pottery vessels clearly derived from metal prototypes which do not as yet exist.

The authors claim that there were migrations of metal-using people in about 1400 BC to Anyang which was at that time unaquainted with metal. It is believed that the reason why the truly primitive metal-using sites have not yet been found is because the earlier sites are not in the areas of most extensive known settlement and, therefore, excavation. They mention that Eneolithic sites have been recently reported which contain a few metal artifacts among long lists of bone and stone. Two such artifacts which were found in Kansu of Chi-Chia date (pre-Shang) have been analysed and found to be of copper and not bronze. What seems to be clear is that Eneolithic sites peripheral to the nuclear area (centred on Anyang) have yielded primitive metal, but their dates are not necessarily earlier than Early to Middle Shang.

The authors consider the recent work of Soviet archaeologists which tend to disprove the earlier held theories about a diffusion route through the Minusinsk region of the USSR. Recent finds here relate to the Karasuk culture which dates to 1200–700 BC. They agree with others that it is more likely that Siberia received some of its metallurgical ideas from Shang China rather than the west, with reverse influences in Eastern Chou times (700 BC).

In consideration of the ore distribution and alloy composition of Chinese artifacts, the authors note that the copper content decreases with time showing the usual Late Bronze Age sequence for cast metal from straight tin to leaded bronzes. Zinc is virtually absent, and iron is low, and we have the usual amounts of minor and trace elements. All this is based on 44 specimens from controlled excavations, the composition of which is given in a single table. Maps are given of known tin and copper ore deposits which appear to increase in density as the nuclear zone near Anyang is approached. One of the outstanding features is the relatively high density of tin deposits within 400 km of Anyang (in Shensi and Honan), but unfortunately no information is given about the existence or absence of tin deposits beyond this area. This concentration is suggested as being an important reason for the use of very high tin bronzes in the Shang period and, according to the authors, of Chinese origins for Chinese bronze casting. This is an argument that I cannot accept. The addition of tin to a bronze in such large amounts (10 to 20% is an intentional act which suggests a pre-knowledge on somebody's part. After all, relatively pure coppers were in use in Cornwall, Italy and Saxony-Bohemia before bronzes based on local deposits were introduced.

Unfortunately we are not told much about the manner of existence of tin and copper in China; especially whether tin is alluvial or deep-mined.

The accidental discovery of ores is alleged to have led to the accidental discovery of smelting by burning and the subsequent casting of such smelted metal in a pottery kiln where the necessary 1100°C could be reached by Shang times. This I can accept, although it overlooks the problems of fluxing. The transition to a more suitable form of furnace would be swift. But what about the use of native copper which was always, and still is, freely available in most of the world's copper deposits? This argument naturally leads to a discussion of pottery kilns and bronze casting furnaces. The discussion on Chou pottery kilns must be one of the most complete that is available in the English language although the types are mostly familiar to the Western reader. Although the evidence for high temperatures is not impressive, I would have no hesitation in accepting the thesis that temperatures in excess of 1085°C were available somewhere in an updraft kiln, and that if crucibles were placed in these areas with copper globules and charcoal in them the metal could be melted. It would not be easy, however, to extract a small crucible and pour it into a mould 1100°C from some of the kilns shown.

Unfortunately the evidence for early melting furnaces in China is not particularly impressive. Only three bronze casting sites have been reported; one is Middle Shang at Cheng-Chou and has yielded mould fragments, crucibles, copper ore, slag and charcoal but no furnace. As no detailed analysis has been reported we cannot tell whether the slag is smelting or melting slag. The 'ore' might be corroded metal.

At Anyang a channel 850 cm long connecting the furnace to the casting pit has been found which implies the casting of very large objects.

The third casting site was Eastern Chou in date (770–220 BC). The four 'furnaces' found were in a badly damaged condition but they sound like pottery kilns. Fragments of crucibles with bronze residue, both inside and out, were found. It seems odd that early furnace remains should be reconstructed like pottery kilns when China has produced perfectly normal melting furnaces in post – Han contexts.

The crucibles seem to be of two varieties. An ogival type with a pointed bottom which was reported by Barnard in his earlier work, and a flower pot shape (80 cm dia.), a type which seems very large and well-capable of casting the large vessels of the Shang and Chou periods. In the reconstruction, this type is shown situated in a pottery kiln with a side pouring aperture connected with a runner or channel. This reconstruction is very ingenious and should work if the perforated floor was strong enough to hold 1,650 kg of molten bronze, which is doubtful. Considering that a similar 'crucible' in the Cyprus Museum at Nicosia has now been identified as a furnace lining, one wonders whether a similar mistake has been made here. This idea is further reinforced by the author's inclusion at this stage of reproductions of Japanese drawings which date to the 19th Century AD. In one of these a smelting furnace is shown which is no more than a hole in the ground with a clay lining. The smelted metal is removed by solidifying the surface with water and removing a thin layer or cake with a hook. Of course, this still leaves us with the necessity of remelting the copper in suitable crucibles for casting. Both square and oblong ingots of tin (dimensions) not given) have been found at Anyang. Copper ingots have been found in Eastern Chou and Han sites weighing from 1 to 4 kg and of rectangular shape (32 x 8 x 1.5 cm).

Barnard has dealt with the subject of moulding at length in his first book, and his theory of clay-piece moulding based on pottery moulding is universally accepted. But moulding was not confined to clay. As in the West, moulding materials used in about 500 BC included metal, and 'clay' consisting of 60% sand and 40% clay fired at 800C. The master pattern (model) was made of clay or metal.

Small parts were pre-cast in bronze and then 'cast-on' to the main artifact by being inserted into their proper position in the mould. The cores and core supports (prints) are arranged in much the same way as in the West. Chaplets were not necessarily metal; in some cases they were triangular clay projections from the core.

As this book is mainly pre-Han we cannot expect much on the subject of iron. But iron casting started about the 7th century BC and iron made rapid strides in late Chan – Kuo times (350–220BC) following the establishment of wrought iron technology in about the 4th century BC.

Now that it has been shown how cast iron could have developed out of copper refining in the West – a necessary demonstration in view of the odd pieces of cast iron dating from the 3rd millennium – it is not so surprising to find that the Chinese knew about cast iron in the 7th Century BC. But of course the extensive use of it was quite a different matter and in keeping with their extensive use of large cast bronzes.

The main item still to be resolved is the earliest date of the introduction of wrought iron and smithing techniques. Was wrought iron a direct product or a result of the conversion of cast iron? Here the authors admit the possibility that wrought iron working was a technique introduced from the West. They admit that pottery kilns would not give the control of atmosphere that was necessary to reduce iron, and this would need the later development which produced a horizontal kiln more like a reverberatory furnace. Yet we know that crucible cast iron and steel were made in later times in a very primitive form of furnace like that used for Wootz in India. It would seem that bloomery furnaces were used in the Han period. All sorts or mixing is suggested, including cast iron and wrought iron to make steel. In Honan, tuyeres were found for the first time in China. The finding of tuyeres leads to a discussion on bellows which were in Han times concertina type pushed horizontally, rather than vertically as elsewhere. Barnard and Tamotsu think that this may be another item of Chinese origin.

Some of the cast iron agricultural tools produced in this period (Chan-kuo to Han) were produced in piece moulds. Others were made in cast iron moulds. Unfortunately we are not given any information about the type and composition of the cast iron. But we do know from elsewhere that in China in this period white cast iron could be malleablised by reheating and therefore would serve as quite satisfactory agricultural implements.

Of great interest is the fact that of 26 iron items found on sites dating from Chan-kuo to Early Han, only 12 were cast; the rest showed evidence of smithing. But no smithing tools have been found.

Finally, the authors deal with other metals and decoration. Lead objects were found in Late Shang to West Chou sites and gold leaf in Late Shang, but no cast gold artifacts. Cast iron has had grooves cast in to take inlay. Silver is almost entirely absent. They assume that the primitive standard of decoration is evidence of local origin.

The work emphasises the co-operation between pottery and metal moulding and casting and the complete lack of smithing work in the early phases. Hardness measurements of cast bronzes (positions not given) all show low as-cast hardnesses (31–100 HB). Riveting was unknown prior to the 5th Century BC. Burning-on was, of course, known while soft soldering was alien to pre-Han China which seems strange considering the knowledge of the two metals tin and lead and the possibility of segregates in castings. Pseudo-granulation was practised in bronze, suggesting that the Chinese had seen examples of the real process from abroad. With such a complete mastery of casting by piece -moulding it is not surprising that lost-wax casting was not known until the 2nd Century BC.

The distribution maps form a section on their own and are designed to take the place of the catalogue of sites as far as the non-Chinese reader is concerned. This has proved to be a very interesting part of the book, and the 'observations' that go with them are very informative.

The maps show the centrifugal nature of metallurgy in China and its concentration around the original 'nuclear area' with the eneolithic sites out on the periphery. On suspects, though, that these suffer from the problem of all distribution maps – they show.only the sites known and not the total sites that exist. But it is true that there are relatively few known eneolithic sites within the nuclear area. First we get the distribution of bronze, then gold, then silver and then iron artifacts of all types. Then the series starts again for certain types of artifact such as chariot and harness parts, swords (iron and bronze) cross-bows, Ko-dagger axes, belt hooks, mirrors etc. Amongst this we get iron coffin nails from Chou-kuo to Eastern Han times (480 BC to 220 AD). Although there is no indication of how the iron nails are made, it is pretty certain that they are wrought iron and not cast iron. Some bronze nails were allegedly cast.

The Table of Sites and Remains in Chinese is followed by a general index to site areas by numbers in English, an index to individual sites by characters, and an English alphabetical index to the individual sites. After the bibliography there is a general index to the English text including the observations on the distribution maps.

One has to praise the authors and their publishers for such a momentous work. The presentation and the clarity of the maps and drawings is impressive. There is little doubt that it justifies the high price of the book. If one has any criticism of the work it is that most of the drawings of the artifacts have no scale (perhaps because there was none on the original reports) and there is no concise table of dates. But one can of course build up one with the aid of the data given in the distribution maps. The most frustrating part is not being able to read the Chinese list of excavated sites because it is clear from the text that, for example, the actual number of pieces of metal dross found on a site is given here and nowhere else.

The serious deficiencies of this book are nothing to do with the two authors. They stem from the lack of information given in the original Chinese reports where, up to about 1960, it was not normal to have a complete analysis of objects and material of metallurgical significance as had been normal in the West. There is little doubt that as science is more widely applied to Chinese archaeology this will be remedied and Professor Barnard and his co-workers will find enough to justify a new edition and, I hope, enough to clear up the problems of furnace types and the early development of Chinese metallurgy.

R F Tylecote

Lesley L Ketteringham. Alstead; Excavation of a 13th–14th century sub-manor house with its ironworks in Netherne Wood, Merstham, Surrey. Res. vol. of the Sussex Arch. Soc. No. 2. Published by the Society at Castle Arch, Guildford, 1975. pp 73, A4 format, Price £1.70.

This is an important work from the point of view of the history of metallurgy as it covers the development of smithing hearths during the period when they changed from low bowl-hearths in the ground to waist-high hearths of the more familiar pattern of recent times.

The house was built in the 2nd quarter of the 13th century (period 1). Now there are only chalk foundations left and the remains of a sandstone and flint wall. This house was demolished in about AD 1270 and replaced by a timber-built hall with a flint-built tile kiln (period 2).

During the first period, smelting and forging were carried out in bowl hearths in a corner of the demesne. In the second period a proper timber-framed smithing house was made and used until the end in the mid-14th century. After a period of about 50 years, the smithing house was refurbished and a large forge constructed on a flint-and-clay platform to the east of the site which was operated until the turn of the century (period 3). The hearth was now about 60 cm off the ground, but the smith's forge had become much more sophisticated showing many of the features that we find in post-medieval hearths. A useful reconstruction is presented together with a discussion on the general development of early hearths with comparison with the documented material.

No metallographic investigation has been carried out on the metal artifacts found but the iron-ware is well-drawn and discussed by Ian Goodall. Coal was found, and an analysis of a rich piece of iron ore gave 59.2% Fe_2O_3 and 22% of $CO_2 + H_2O$.

This is a useful piece of work at a reasonable price although the absence of detailed metallographic work is disappointing. Clearly every attempt has been made to make this report available at as low a price as possible; it is a good example of the way an archaeological report can be made available to the public at a price the majority can afford in contrast to the current spate of more glossy and expensive volumes at £25–35.

R F Tylecote

Notes on the Prehistoric Metallurgy of Copper and Bronze in the Old World. by H H Coghlan. Edited by T K Penniman and B M Blackwood. Occasional Papers on Technology 4, Second Edition, 1975. Pitt Rivers Museum, University of Oxford. Price £3.00.

The preface to the second edition of this well documented publication itself gives a good indication of the broadening field of research since the first edition appeared in 1951. Without having attracted any particular label comparable to 'the new archaeology', investigations of prehistoric metallurgy have clearly been moved towards detailed scientific examination of artefacts even when this necessitates the cutting-out of test specimens, and subsequent restoration, and actually trying to work hypothecated prehistoric techniques such as smelting and casting methods. In this, the principal author, as at once an engineer and a museum curator, has long given a strong lead.

The advances in knowledge just foreshadowed are partly reflected in a greater length of text (pp 145 compared with 120), but more in the complete rewriting of over half of the chapters. Those that are unaltered include factual reports on examinations of some individual artefacts. Penniman has extended his still-brief, beautifully illustrated chapter on lost wax casting, to include a bronze flying horse so admired in the Chinese Exhibition of 1973–74.

Although there is the necessary warning against accepting archaeological dates without reservations, the evidence summarised by P R S Moorey and supported by R F Tylecote points to the emergence of metallurgy, properly so called, in the Near East far back within the 4th millennium BC, and there is increased recognition of the long period of use and importance of arsenical coppers. Differing views are noted on whether the alloys of the higher arsenic content had needed to be deliberately made, or whether they could have resulted directly from the smelting of arsenic bearing copper ores.

Tylecote draws attention to the appearance of true tin bronzes on widespread sites on the Euphrates–Tigris Delta in 3000 – 2500 BC, but the sources of tin and method of alloying it remain debatable. On this latter point, balance of opinion favours the reduction of the oxide ore of tin, cassiterite, in molten copper under charcoal. No substantial progress is reported on tracing metals back to their sources from compositional evidence: here the petrologist locating the sources of stone axes has had the immense advantage of dealing with materials unaltered in composition and microstructure by their quarrying and use.

In the first edition it was possible for Witter to be quoted as giving 6% tin as the upper limit in a bronze for cold working, but this position could not now be sustained. For instance the edges of many tools of higher tin content show evidence of having been hardened by cold hammering, and one can have no reasonable doubt that the purpose was to sharpen them and to produce more lasting edges.

Indications are given on what should be looked for when analyses are being made, and sampling and specimen preparation for metallography are outlined. The text reflects the increasing knowledge of smelting furnaces and, as in the 1951 edition, describes the equipment and probable methods used in producing and fabricating the metals. Crucibles remain something of an enigma as those that have been described are generally small in relation to many artefacts such as axes. Jointing techniques such as riveting and soldering appear to have reached a quite sophisticated standard. The early appearance of a form of lathe, and spinning as a fabrication method, and the comparatively late discovery of brass may surprise some readers.

With the present economic climate so adverse to specialised technical publication, it was a joy to handle a publication produced to older, better standards worthy of its high quality contents, and because of his special interest, for this reviewer to see such well – produced illustrations. Photographs are usually by far the worst sufferers when the publisher must use modern economical printing techniques.

George Parker

A Raistrick. The Lead Industry of Wensleydale and Swaledale Volume One: The Mines. Moorland Publishing Co., Hartington, Derbyshire. 1975. 120 pp, including 10 maps and 45 illustrations: 22 x 15 cm. £2.95.

The second volume will be devoted to smelting. Both Moorland in its fourth year, and Raistrick in his eightieth, deserve much credit and support for continuing to produce studies of local industrial archaeology which the economics of publishing are causing other established houses to avoid. This first volume is a revised and extended version of Dr Raistrick's (1955) **Mines and Miners of Swaledale**, and will be of especial value to those with a general interest in mining and metallurgy, or who just enjoy the Dales.

Moorland were recently criticised rather harshly by Mutton in this journal, and to some extent his strictures unfortunately apply to this volume also. Though the paper and print are of high standard, the photographs have less than the original sparkling quality, and a few, as the remains at Beldi Hill (p34) ought not to have been introduced, whilst some of the ten or so adit entrances could have been omitted without damage to the whole. But if as it seems to be, the alternative is very few photographs on art paper, then I for one prefer the valuable historical record which most of these represent: for instance H M Parker's Sir Francis Engine. Line drawings, a Moorland speciality, are of a consistently high standard.

The content divides into two major parts – the first is a technical and largely chronological introduction, the second and most valuable, a description of the mines in the main areas. A chapter on coal and copper mines fits unhappily with the title, the more so since it is almost as long as the section devoted to the Wensleydale Lead Mines. The last chapter, 'The Miners' appears something of an afterthought, which perhaps a thematic rather than chronological introduction might have overcome. Having separate volumes, necessary though it may be commercially, has led to the paradox of having as much on smelting in this volume, as on ore dressing.

A few points are irritating to the specialist. No grid references are given for the sites. The air receiver at Sir Francis was for the drills, not the hydraulic engines. (p53) It is surely time for other theories of mineralisation to be given as much prominence as the end products of the cooling of magma. (p11–12) The nineteenth century is curiously neglected in the chapter headings, whilst an unfortunate proofing error, page 28, and repeated page 42, has nineteenth century ore dressing improvements attributed to the previous century.

At £2.95 in hardback, this volume reflects the general increase in prices, and is comparable with other publishers'. Despite its imperfections, it reflects Dr Raistrick's wide knowledge of the subject and area, and provides an interesting and readable account of mining in the Dales.

Lynn Willies

R Flindall and A Hayes. The Caverns and Mines of Matlock Bath. 1. The Nestus Mines: Rutland and Masson Caverns. Moorland Publishing Co. Buxton, Derbs. 1976. 21 x 15 cm. 77 pp, 24 photos, 16 maps and diagrams, glossary, index. Price £1.10 paperback.

Essentially this is a lead mining book with local history additions to widen its appeal. An introductory chapter covers geology and an outline history whilst the next two chapters deal with the mines and caves.

Written records of mining begin here in 1470 although earlier mining is highly likely. In the 16th century three mines were highly productive with an estimated output of 7000 tons of lead ore. Subsequently production varied with the usual factors of exhaustion, discoveries of new veins, techniques and the market price of lead ore, finally ceasing around 1900. Some calamine was raised for brass making prior to 1840 whilst fluorspar was being sold as a by-product from the Crichman Mine in 1790 for unstated uses. Since 1900 fluorspar has been exploited in response to the demands of the steel industry.

Perhaps of interest to historical metallurgists is an iron object described on page 28. This was found in about 1767 and described as an anvil dating from 1051. It certainly bears no resemblance to any known mining tool whilst its small size and unlikely looking legs do not point to its suggested use.

The format of the book closely resembles that of the Pound House series on Mid Welsh Mines, ie that of a low priced paperback, attractively presented and containing a wealth of information. The standard and interest of the numerous illustrations is good but on many occasions no reference is given for authoritive statements in the text. There is no bibliography but perhaps this will be included in further issues in the series.

I J Standing

Andreas Oldeberg. Die altere Metallzeit in Schweden. Kungl. Vitterhets Historie Och Antikvitets Akademien. Stockholm. Vol. I. Catalogue. 1974. 410 pages of text, plus 240 pages of illustrations. Vol. II. 1976. 224 pages. Many illustrations, tables etc.

Dr Andreas Oldeberg needs no introduction as a leading authority on metals and their technology in Sweden. As well as a large number of papers many will remember his important work entitled 'Metallteknik under Forhistorisk Tid', in two volumes, published in 1942–43. The present work, written in German, dealing with non-ferrous metal artefacts, etc, of the early metal age in Sweden, may be said to be in two parts. Volume I is a monumental illustrated catalogue representing many years of work. In this catalogue a vast range of tools, weapons, and decorative work will be found, forming a most valuable typological source reference. Well over 3000 artifacts are illustrated by clear line drawings to scale.

The second volume, also with a considerable number of illustrations, treats of the technological and metallurgical aspects. In chapter I, tools, weapons and decorative work are considered, while in chapter II graves, burial customs, and religion are considered. In chapter III the various metals, copper, arsenical copper, tin, lead, gold, zinc, are discussed; space is also devoted to problems of dating, analyses, casting and mechanical working. Particularly welcome are a large number of new analyses of copper and bronze objects from Sweden and others from the Mediterranean region, etc. The importance of arsenical copper in prehistory is generally accepted and these analyses lend support to this view. Useful notes are given concerning prehistoric artifacts which contain a high percentage of zinc in their composition, and of the various places in which zinc containing minerals such as calamine are found. Zinc containing ores are by no means uncommon in Europe and the Near East. The possibility that objects containing high zinc may be fakes or copies has often been mentioned. However, as Dr Oldeberg correctly points out, it cannot be taken for granted that pre-Roman artefacts with high zinc content are fakes or copies. On the other hand, when the zinc content of an object takes it into the category of a brass it is well to check the authenticity by means of metallographic examination.

On page 50 of vol. II, the old British Association Committee on the composition of ancient metal objects, and the Ancient Mining and Metallurgy Committee of the Royal Anthropological Institute is mentioned, but I cannot find any reference to to the very active Historical Metallurgy Society which is associated with the Metals Society, London, and who issue a Journal in which much research is published in the field of ancient ferrous and non-ferrous metallurgy.

In this work there are too many matters of technological interest to be dealt with within the limits of a review. For instance, questions concerning the problems in the evolution of the various axe types. Also, casting techniques including cire perdue casting which was known at such an early period. In passing, it may be remarked that, in the reviewer's opinion, Leon Underwood's idea that all bronze moulds were used to prepare wax models for cire perdue casting is very questionable since experiment has shown that bronze moulds are quite suitable for the direct casting of bronze.

In conclusion, these two volumes are highly recommended. They are certainly essential reading for the technologist, and also the metallurgist who is interested in the field of the early non-ferrous metals will surely find much of interest and value in them.

H H Coghlan

Guy Hadley, Citizens and Founders. A History of the Worshipful Company of Founders, London 1365–1965. Phillimore 1976. £12.

The history of a thriving institution which has evolved from a medieval guild of brass casters is obviously within the range of interests of members of the HMS. This book, published in a limited edition, has been written primarily for those concerned with the Livery Company as such and the author has chosen to relate its development to the broader framework of English history. Although the precedence given to Citizens in the title reflects the emphasis, previously published extracts from Guidhall records and the Wardens' Accounts for 1497–1681 have been drawn on extensively.

The Founders Company seems to have been typical of many of the Livery Companies with trade origins as distinct from the more powerful Companies with merchant backgrounds. Apart from the control of trade monopolies and the welfare of their members, Guilds were involved in an early form of representative local government. For these privileges, they incurred taxes imposed by the Crown and by Parliament from time to time. The Founders built their first Hall around 1540, obtained a Royal Charter in 1614 and gradually lost their close connection with the foundry industry as time went by. A glance through the list of Masters suggests that, in common with other City Guilds, they were not controlled by family dynasties, but without a full list of liverymen, the evidence is inconclusive. The liverymen, who were in a minority and in the 16th Century formed less than one third of the total membership of around a hundred, were a self-perpetuating oligarchy but drawing their members from the Yeomanry whose two classes are regarded as comprising the master craftsmen and the journeymen.

In 1587, the Founders managed to obtain a formal agreement that weights offered for sale in the City must be 'sized' at their Hall and bear their stamp. Attempts to get lead weights replaced by brass were unsuccessful. The right to supervise weights in the City was zealously preserved even when it was no longer enforced and the Company's position is formally acknowledged in Acts of Parliament of 1878 and later years.

A succint postscript on the technical evolution of the foundry industry has been contributed by Michael Hallett, known to us in other roles, but on this occasion wearing his livery.

Norman Swindells

Abstracts

GENERAL

K C Barraclough. **The development of the cementation process for the manufacture of steel.** J. Post-Med. Arch. *1976,* **10,** *65–88.*

The cementation process for making steel is shown to have been a German invention of the late 16th century. The author surveys its early history and its introduction into England. He describes the different types of cementation furnaces, some of which remained in use into the 20th century.

H H M Pike. **Pottery firing temperatures.** Archaeometry, *1976,* **18** *(1), 111–114.*

Calculations allowing for heat losses show that it would be very difficult to exceed 900°C by burning charcoal under reducing conditions in a simple kiln. Much higher temperatures can be reached under oxidizing conditions and hence one could smelt and melt copper in a covered crucible, containing some charcoal, placed in an oxidizing flame above the fuel.

C S Smith. **Some speculations on the corrosion of ancient metals.** Archaeometry, *1976,* 18 *(1), 114–116.*

It is suggested that the electrochemical diagrams used by Marcel Pourbaix to define regions of passivity can conveniently be considered as sections through conventional multicomponent phase diagrams, using as components e^-, 0^{--}, H^+, and the most highly ionized state of the other anions and cations. Corrosion of objects over very long periods of time is more akin to mineral formation than to industrial corrosion. Even in regions where passivity is electrochemically favoured, physical factors (most notably the tendency towards interface energy equilibrium) will often enable corrosion to continue.

L White Jr. **The study of medieval technology, 1924–1974: personal reflections.** Technol. Culture, *1975,* **16,** *519–30,* refs.

Serious work on medieval technology began c 1931 with a further impetus in the mid-1950s, and modern editions of pre-1500 texts began to appear at the same time. By now it is clear that the late 15th-century European explorers were soundly backed by the technology of ships, navigation, armament, agriculture and manufactured goods.

See also author's Medieval engineering and the sociology of knowledge. Pacific Hist. Rev, 1975, 44, 1–21.

H C Nisbet. **A geological approach to vitrified forts: Part 2, bedrock and building stones.** Sci & Archaeol, *1975,* **15,** *3–16, tables.*

Provisional list of vitrified and timberlaced forts with notes on rock substrata and building stone. Siting is not influenced by purely geological factors, though most forts use only or mainly the rock found on the spot. Vitrification has been achieved in a wide variety of rocks; the necessary temperature would be in the range 1040°–1215°C.

S R B Cooke and S J Aschenbrenner. **The occurrence of metallic iron in ancient copper.** J. Fld. Archaeol, *1975,* **2,** *251–66, pls, figs, table, refs.*

Coppers with high iron content (more than 1 or 2%) occur in Chalcolithic–BA–EIA contexts in the Mediterranean and India. It is suggested that the iron was introduced as a result of simultaneous reduction to solid metallic iron or iron oxides in the furnace charge as copper smelting proceeded; the phenomenon may have been quite widespread. The discovery may allow the determination of the maximum temperatures attained by charcoal smelting furnaces, but spectrographic analyses may mislead owing to segregation.

H A Waldron, A Mackie and A Townshend. **The lead content of some Romano-British bones.** Archaeometry, *1976,* **18** *(2), 221–227.*

Lead levels in ribs from the Romano-British sites at Poundbury and Henley Wood were measured using atomic absorption spectroscopy. The Poundbury bones contained a mean concentration of 112.7 ppm of lead whereas the mean in those from Henley Wood was 65.7 ppm. In both series, mean levels in males were higher than in females but an increase in lead content with age was noted only in the Poundbury bones. The results of this study suggest that the people who lived at both these sites were exposed to levels of lead in the environment greater than those of the present day.

A Hartmann and E Sangmeister. **The study of prehistoric metallurgy.** Angewandte Chemie, *1972,* **11** *(7), 620–629. (in English).*

A very useful and succinct summary of the conclusions of the 'Stuttgart Group' for ancient metallurgy of the Roman-Germanic Museum. Based upon work carried out over the last 20 years and reported in detail in Studien zu den Angfangen der Metallurgie, 1960, 1968, and 1970. It deals with copper-base alloys and gold. RFT

BRITISH ISLES

D Crossley. **Cannon-manufacture at Pippingford, Sussex: the excavation of two iron furnaces of *c* 1717.** Post-Medieval Archaeol., *1975,* **9,** *1–37, pls, figs, tables, refs.*

TQ 450316. Two blast furnaces produced iron in early 18th century: one was casting guns, the other pig-iron, and there was also a boring mill with its carriage in place on the tracks. The making of cannon is described, and the results of tree-ring analyses are reported, together with descriptions of the pottery, gun-mould fragments, glass, metal objects, ores and slags.

J M Lindsay. **Charcoal iron smelting and its fuel supply; the example of Lorn furnace, Argyllshire, 1753–1875.** Journal of Historical Geography, *1975,* **1** *(3), 283–98.*

This paper is adapted from the author's 'The use of woodland in Argyllshire and Perthshire between 1650 and 1850' (PhD thesis, Edinburgh, 1974). The paper opens with a brief summary of iron smelting in the Scottish Highlands where evidence is advanced to question the validity of the accepted views. Originally it was thought that the industry had grown up because the English ironmasters, who controlled the industry, were compelled to seek new sources of charcoal when they had exhausted their domestic supplies; as a result the woods in the Highlands were considerably depleted. On the basis of archaeological evidence Dr Lindsay thinks there was real management of timber resources to make them last and that Highland bloomeries were small domestic production sites and that many were short lived.

He then describes the Lorn furnace in detail: its foundation, site and situation. The next section is a detailed account of fuel consumption and output. The paper concludes with an account of the fuel supply and the effects of the furnace on the sources of fuel.
PSR

P S Richards. **The Hawarden Bridge Iron and Steel Works, Shotton, Chester of Messrs. John Summers & Co.** Journal of the Flintshire Historical Society, *1971–2,* 25, *103–43.*

This paper is adapted from the author's thesis 'The Deeside of North Wales – A study in Industrial Location' (MPhil. London 1973). It deals with the growth of the industry from its early days in Dukinfield when John Summers made clogs for local cotton workers. He bought a nail-making machine from the Great Exhibition of 1851 for £40 (to make the nails for the clogs) and so began an enterprise which was to end in the setting up of a fully integrated iron and steel works.

Summers moved to Stalybridge and at the turn of the century to the present site on the Dee flats at Shotton where land was either cheap to purchase or cheap to reclaim. This paper traces the introduction of the newest methods of iron and steel production accompanied by the fullest consultation with the Trade Unions. The drainage of the site, the railways on the site, the import of raw materials and the export of finished goods – first to overseas markets and then after 1939 to the home market are discussed.

There is a detailed analysis of the raw materials used and the fuel required. The paper concludes with the reasons for the location of this firm: the only fully integrated iron and steel works not on an orefield, not on a coalfield, not on a navigable waterway nor on the coast. The site and the good labour relations together with highly mechanized plant are the reasons for the success of this enterprise.

(**The Journal of the Wilkinson Society**, 1975, (3), 9–11 contains a paper by the same author on John Summers as an entrepreneur.)

M C S Evans. **Cwmdwyfran Forge, 1697–1839.** Carmarthenshire Antiq, *1975,* 11, *146–76, pls, figs, refs.*

The charcoal iron forge built in 1697 survived until converted to a cornmill in 1839. Its mill leat led from a large stone dam 400 yds upstream to the mill-pond, now reduced in size, which fed two waterwheels: a 10 ft one for the 37ft hammer beam, and a 16ft wheel for the air-blast. Capacity was nominally 120 tons/year. The shell of the forge building remains, and employees occupied five nearby cottages. An inventory of 1808 and accounts of 1802–10 provide much useful evidence.

D S Butler and C F Tebbutt. **A Wealden cannon-boring bar.** Post-Medieval Archaeol., *1975, 9, 38–41, figs.*

TQ 555155. An 11ft bar removed from Stream Mill, Chiddingley, has been conserved and placed in a museum at Lewes. The bar is precision-forged in wrought iron with cutters designed to increase an extant boring to 130 mm diameter. Metallurgical analysis of a cutter is reported.

B C Skinner. **The archaeology of the lime industry in Scotland.** Post-Medieval Archaeol., *1975, 9, 225–30, pls, fig.*

Deals with the late, highly capitalized industry of 18th century onwards and suggests the main points to be covered by any field survey, eg. site, source, haulage, kiln plan, kiln-head, construction, vents, etc.

C L Curle. **An engraved lead disc from the Brough of Birsay, Orkney.** Proc. Soc. Antiq. Scotland, *1972–4 (1975)* **105**, *301–7, pl, figs, refs.*

A 50mm lead disc, decorated on one side with trumpet-spirals, came from below a complex of Norse houses and is provisionally identified as a casting-pattern and discussed in relation to the two-piece brooch moulds from Birsay with their innovatory pouring-gates.

D R Walker. **The metrology of the Roman silver coinage: Part 1, from Augustus to Domitian.** Brit. Archaeol. Rep. Suppl. Ser., *1976, 5, 159 pp, figs. tables, refs.*

First of a series of reports on large-scale analyses using X-ray fluorescence spectrometry. As the purpose is mainly to establish silver content, only the major metals (silver, copper, some lead and tin) are examined.

D F Allen. **Cunobelin's gold.** Britannia, *1975,* **6**, *1–19, pls, fig, tables, refs.*

Thorough study of dies from this fine coin-series (159 staters, 36 quarters) reveals that five distinct series were issued, not in the order an art historian would expect. Specific gravity analyses indicate good mint control, and it is estimated that about one million staters were coined from about 3000 Roman pounds of fine gold over a period of 30 years. Hoarding was almost unknown apart from the Epping Forest example.

P Archibald and C F Tebbutt. **A Bloomery Smithy Hearth at Etchingwood, Buxted.** The Sussex Arch. Soc., *1975,* **113**, *190–191.*

In ploughing a field a large lump of iron slag led to the discovery of an oval pit, one half of which showed that it had been subjected to great heat and which contained some slag, pieces of iron and some charcoal. The north half of the pit had a floor of molten slag with some slag packed into it. This may have been a hearth in which raw blooms were worked. Probably of medieval date.
ECJT

A G MacCormick and L Willies. **A 'Great Pig' of lead found near Colwick, Nottinghamshire.** Bull. Peak District Mines Hist. Soc., *April 1976,* 6 *(3), 144–145.*

A stamped, boat-shaped lead pig weighing 3 cwt found in gravel pit north east of Colwick Hall and near old source of River Trent. It is elliptical in plan with a carinated cross-section; ends have been hammered to form a corve, possibly for rope slings. Underside is pitted and it appears to have been cast in a gritstone mould. Of late 17th or early 18th century date. The inscription is either WL or LW repeated many times.
ECJT

B Cunliffe. **Iron age communities in Britain.** London 1975.

An account of England, Scotland and Wales from the 7th century BC until the Roman conquest. Remarks on iron using, smelting and working (p. 267). First iron objects appear during the 7th century BC. Some ancient finds mentioned (Llyn Fawr, Walthamstow, Cold Kitchen Hill), furnaces (Kestor, West Brandon) and later currency bars.
CPSA

I M Stead. **A bronze brooch-blank from Baldock, Herts.** The Antiquaries Journal, *1975,* 55, *(11), 397.*

Detailed description of a brooch-blank from a Romano-British site is given, thought to be unique in England. A brooch-manufacturer's workshop in vicinity. Reference given.

M U Jones. **A clay piece-mould of the Migration Period from Mucking, Essex.** The Antiquaries Journal, *1975,* 55 *(11), 407–408.*

The fragments of the clay piece-mould came from the fill of a sunken hut of the pagan Saxon period. They form the front and back halves of a mould for a great square-headed brooch. Comparisons are made with Helgö, Sweden and it is suggested that itinerant metalworkers might have played a part.

J Musty. **A brass sheet of first century AD date from Colchester (Camulodunum).** The Antiquaries Journal, *1975,* **55** *(11), 409–411.*

A brass sheet with stamped inscription containing 27% Zn is described. Analysis reveals it to be an alpha brass and it is a well-homogenized and worked solid solution with twinned grains and a hardness of 97 HV 5.

The structure is very clean with almost no slag but there is marked de-zincification near the surfaces with some grain boundary corrosion. The surfaces also contain some decorated slip bands but there was little sign of final cold work in the centre of the specimen. It is clearly a thoroughly worked and annealed piece of metal with some final planishing of the surface.

L E Webster and J Cherry. **Medieval Britain in 1974.** Medieval Archaeology, *1975,* **19**, *220–260.*

Iron working sites in Bedford (some evidence on iron smelting at Midland Road, P. 243), Norwich, Norfolk (industrial activity with iron objects and slag, 11th–12th centuries at Colegate, p. 247), and at Godmanchester, Cambridgeshire (Huntingdonshire) – 13th century buildings; one served as a black-smith's shop. Remains of 4 shaft furnaces for smelting iron ore in the rear of the complex.

Simon Stevens. **Major discovery of Bronze Age implements at Dover.** Kent Arch. Rev. *1976 (43), 67–71.*

90 objects of bronze were found during diving near Dover Harbour. The group is of Middle Bronze Age date, 1200–1000 BC and consists of flat winged axes, spatulate axes, daggers, palstaves, spearheads etc. It is suggested that the objects were in transit to Britain and had formed a cargo lost at sea. For some of the axes a Central European origin is suggested. RFT

M Schofield. **A Versatile Ironmaster.** Foundry Trade Journal. *1976,* **141** *[3100] 1109–1112.*

Aaron Manby, born 1776 at Albrighton, Shropshire founded the Horsley Ironworks near Tipton, Staffordshire, where he began building his first iron steamboat. The French government banned the import of completed iron ships, so Manby sent iron sections for assembly to Charenton near Paris where he later established a full scale iron industry. In 1826 he went on to acquire the famous Creusot ironworks, first established by the Wilkinsons, and later played an important part in supplying gas for illuminating the streets of Paris.

Another of his patents was for the production of building bricks from blast-furnace slag.

APG

P M Dinsdale. **"Let Freedom Ring" – the manufacture of the Bicentennial Bell.** Foundry Trade Journal, *1976,* **141**, *[3096], 690–692.*

A brief history of the Liberty Bell, cast in the Whitechapel foundry in 1752 as a result of a commission from the Assembly of the Province of Pennsylvania to commemorate the 50th anniversary of the province's existence under William Penn's Charter of Privileges, is appended to a description of the manufacture of the new bicentennial bell. The original bell was sent to Philadelphia, but cracked on the first stroke of the clapper. The bell was re-cast by two local men, who at first added 1½ oz of American copper to every pound of the original metal, with the aim of making the bell less brittle, but as a result the sound of the bell was at the time described as a "bonk". The metal was re-melted again, and five pounds of silver added before re-casting to improve the tone. In 1835, the bell cracked again when tolling the death of Chief Justice John Marshall: further damage was caused in 1846 when it was rung again for George Washington's birthday. The results of a radiographic examination of the bell are described by E T Clarke, Foundry Trade Journal, 1976, 141 (3091). APG

Anon. **Modern Material Aids Restoration of Church Bell** Foundry Trade Journal, *1977,* 142 *[3105], 350–351.*

The tenor bell of St Mary's Church, Hadleigh, cast in 1680 and weighing 3,000 lb, was declared unsafe and removed from the tower early in 1976 because of a defect in the top or crown of the bell. Repairs were effected by filling the imperfections with an Araldite epoxy resin filler. APG

S Tyson. **Notes on Cast Iron Aqueducts.** J. Railway and Canal Historical Society, *1975,* **21**, *54–61.*

A survey of, and brief historical notes on, many of the cast iron aqueducts of Britain's canal system.

APG

P. Weaver. **Further Notes on Cast-Iron Aqueducts.** J. Railway and Canal Historical Society, *1977,* **23** *(1), 6–11.*

Includes extended notes in the Pontcysyllte Aqueduct, with special reference to the problems at the southern abutment, which have recently been again responsible for the closure of the aqueduct. APG

EUROPE

J Piaskowski. **Iron technology in West Pomerania from late La Tène to early Roman times.** Materialy Zachniopomorskie, *1972,* **18**, *81–135. (in Polish).*

82 objects from 25 sites were investigated. The results of the analyses show that high phosphorus bog iron was smelted. The appearance of the slags indicate that the ore was smelted in primitive hearths. The objects can be divided into three groups. The first group shows a high phosphorus content (ca. 0.2–1.0%) usually with a ferritic structure and slight carburisation (up to 0.2% C). The second group has a low phosphorus content with part carburisation (up to 0.2% C), some nickel (up to 0.13% Ni) and Cu (up to 0.09% Cu). The third group consists of objects of hard steel (0.4–0.8% C, evenly carburised) with a low phosphorus content (0.02–0.13% P).

ECJT

C E Conophagos. **An overlooked method for the cupellation of argentiferous lead used by the Early Greeks.** *(in French).* Ann. Geol. Pays Helleniques, *1960,* **11**, *137–149.*

Examines the reason for blocks of litharge found near Laurion with holes down the centre. It was found that these blocks or bars had been made of many layers and the author has come to the conclusion that they represent a method of removing excess litharge from a cupel to expose the lead and speed up oxidation by putting in iron bars and allowing litharge to solidify on them. The lump was knocked off the bar and the bar reused. It is claimed that this technique has been described by Pliny in the 1st Century AD. Includes data on materials used, finds, and organisation of the lead-silver mines. Details of tuyeres and remains of furnaces. Gives analysis of litharge, lead pigs and slag.

A very useful paper and more embracing than its title would suggest.

RFT

J Lang and J Price. **Iron tubes from the late Roman glass-making sites at Merida (Badajos), in Spain.** Journal of Archaeological Science, *1972,* 2, *289–296.*

Ferritic metal with different grain sizes; welded together from separate iron sheets. Contains nitrides.
CPSA

S N Korenevski. **Bronze age shaft-hole axes from the north coast of the Black Sea and Middle and Lower Volga.** Sov. Ark. *1976 (4), 16–31 (in Russian)*

The 73 shaft-hole axes examined can be classified into three groups and show a wide distribution. Analysis of 44 of these showed them to be of arsenical copper and nearly all of these were made in the Caucasus. In each group are found axes with a low As content (less than 0.6%) and all are the products of local metallurgy made by the smiths on the north coast of the Black Sea. Their composition and the originality of their form show that they were traded amongst the tribes of the Catacomb Culture in the Dnieper and upper Don region, as well as amongst the Poltavkino culture of the Volga. These cultures can be dated to from the 1st half to the middle of the 2nd millennium BC. This gives a date to these axes, and their production ceased with the disappearance of these cultures in the course of the 2nd half of the 2nd millennium BC.

A table of 22 analyses, showing As contents in the range of 0.25–3.5% is given. Unfortunately only the site from which the object came is stated and it is not possible to relate a particular object to its analysis.
ECJT

G. Weisgerber. **Representation of mining on Corintian clay plaques.** Der Anschnitt, *1976,* 28, *38–49. (In German).*

New interpretation of clay plaques of the archaic period (end of the 7th and beginning of the 6th century BC, ie. between 630–570 BC) hitherto thought to represent ore mining and smelting furnaces, now shown to be votive offerings by the famous Corithian potters, depicting scenes of clay mining and potters' kilns.
ECJT

H W Catling and R E Jones. **Analyses of copper and bronze artefacts from the Unexplored Mansion, Knossos,** Archaeometry, *1977,* 19 *(1), 57–66.*

A wide range of bronze and copper artefacts and samples of scrap and waste from the Unexplored Mansion at Knossos in Crete were analysed non-destructively by X-ray fluorescence. The Unexplored Mansion was occupied principally during the second half of the fifteenth century BC and the bronzes belong to the end of the period when Minoan copper and bronze metallurgy was at its peak. It was at this time that Knossos was under Mycenaean control and influence. The analytical data showed that tin was the only alloying metal used in the preparation of the bronzes, but it was found that a significant proportion of the samples analysed were composed of copper alone. Correlations were made between the tin content and the type and intended function of the artefact. The results were used in a few cases to alter or modify the identification of artefacts.

T S Wheeler, R Maddin and J D Muhly. **Ingots and the Bronze Age copper trade in the Mediterranean: A progress report.** Expedition, *1975,* 17; *31–38.*

General discussion on work undertaken by various research groups on metallurgical problems of the Bronze Age. The authors have selected copper ingots for their research and give a list of find places and discuss the possible sources of copper from which they were made. New analysis of ox-hide ingots.
ECJT

M Ahlberg, R Akselsson, B Forkman and G Rausing. **Gold traces on wedge-shaped artefacts from the late Neolithic of southern Scandinavia analysed by proton induced X-ray emission spectroscopy.** Archaeometry, *1976,* 18 *(1), 39–49.*

Visible coloured traces on the surface of two selected wedged-shaped artefacts (pendants) of slate from the late Neolithic of southern Scandinavia were analysed by means of proton induced X-ray emission spectroscopy (PIXE). PIXE is shown to be a feasible tool in investigating surface layers of archaeological significance. Three different gold-silver alloys were found on the two pendants. The results indicate that we shall have to reconsider the generally accepted theories of the economic basis of the early Bronze Age in the area.

J Piaskowski. **Metallographic examination of iron objects from cemeteries of the "Cloche Grave" culture.** Wiadomosci Archeologiczne, *1975,* 40 *(1), 63–84. (In Polish).*

Thirty analyses of iron objects from Masovie, Poland (1st Cent. AD). No tools but ornaments and metal parts of wearing apparel. Low phosphorus iron or heterogeneous steel. Interpreted by the author as imported objects from the Holy Cross Mountain centre.
CPSA

M Grenier. **Finds from an excavation of a Gallo-Roman site at Chaille-en-Brie-Calagum (Seine-et-Marne).** Bull. Soc. arch. champenois, *1975,* 68 *(4), 50–57. (In French).*

A smithy was discovered inside the foundation of a small hut with a hearth in the centre and a pile of slag and some blacksmith's tools (Hammer, cold chisel, etc). 2nd-3rd century AD.
CPSA

Paul T Craddock. **The composition of the copper alloys used by the Greek, Etruscan and Roman civilisations.** Journ. Arch. Science, *1976,* 3, *93–113.*

This paper is the first of four parts dealing with the composition of copper alloys used in the classical world. There is a discussion of previous analytical work and the use to which the analytical data may be put. For published compositional analyses to be of use it is essential that details of the sampling, analytical procedure and standard deviation of the results be reported. The reasons for this are discussed in detail with examples from literature where failure to do this has made the interpretation of the reported analytical results difficult if not impossible.

In this part of the work the composition of about 300 Bronze Age and Geometric Greek bronzes are reported. The data are arranged chronologically within broad limits, and further subdivided typologically. There is a discussion of the results of each group from which it is possible to discern trends in metal composition. The composition of individual objects is also discussed where it is of importance or unusual.
PTC

A Mutz. **The Roman smith and his craft.** Augster Museumshefte 1, *Augst, 1976. (In German).*

A booklet demonstrating the Roman blacksmith's work from examples found at Augst-Colonia Augusta in Switzerland. Blacksmith's tools: Hammers, tongs, files, rods, bars, anvil. Iconographical representations of blacksmiths (Terra Sigillata from Rheinzabern, smithy from the Domitilla-Catacombs at Rome).
CPSA

J Piaskowski. **Metallurgical investigation of iron objects of the Jastorf culture and Lebus group of the early Roman period.** Mat. Zachodniopomorskie, *1972, (1976),* 18, *59–80. (In Polish).*

Examination of 27 iron objects ie. belt-hooks, spears and knives and one sword. Mainly simple techniques of working low carbon materials with a high P-content. The objects are dated to the first centuries AD.
CPSA

H Mamzer. **Metallographic examination of weapons from a hillfort at Styrman, East Bulgaria.** Slavia Antiqua, *1973,* 20, *125–129.*

A short account of weapons examined; mainly arrowheads made of wrought iron or medium steel, rarely of faggoted metal. 9th – 10th cen. AD.
CPSA

O M Prichodnyuk. **Slavs in the Podol region.** *Kyiv 1975. (In Ukrainian).*

Material culture of the earliest Slavs (6th-7th cent.. AD) in the western Ukraine. Apart from the well known site of Gayvoron, seven other sites have been found with evidence of iron working. The smelting furnace of Bakoti is described (dome-shaped, with stone and clay walls).
CPSA

E Sangmeister. **The beginnings of metallurgy in Europe.** Monograph d. Röm. Germ. Zentral Museum, *1975,* 1 *Pt.3, 297–299.*

Stages in the development of metallurgy are described, beginning with native copper as a preliminary to metallurgy which only starts when copper was smelted from the ore. Preliminary knowledge was acquired from Asia Minor and the Aegean and grew into an independant metallurgy in Europe. Development is divided into 6 phases with maps illustrating the various alloys used.
ECJT

H Mamzer. **Problems relating to the ancient and early medieval metallurgy of iron in Bulgaria.** Kwart. Hist. Kult. Mat. *1976,* 24 *(2), 295–305. (In Polish).*

A critical review concerning the conference on the history of technology held in Bulgaria in 1972. Written sources, mainly of the Thracian and Roman periods were discussed as well as the Saxon influence on iron ore mining in the 13th century AD. The period of the 9th–10th century was omitted.

R Pleiner. **Investigation of iron slags from the furnaces at Dubeč, Bohemia.** Arch. rozhledy, *1976,* 28, *276–278.*

The chemical composition of iron slag from furnaces VI and VII at Dubeč indicates the production of a relatively soft and malleable wrought iron with low P and Mn content.
CPSA

R Pusch **A history of metallography.** Düsseldorf, *1976. (In German).*

This book deals with the modern history of a scientific method for the investigation of metal artifacts and is a complementary study to its famous forerunner of the same title by C S Smith of the MIT, Massachusets, USA published in 1960 & 1965.

CPSA

W Szymanski. **Ironworking amongst the eastern Slavs.** *(In Polish).* Wrodaw – Warszawa – Krakow – Gdansk, *1973.*

General discussion on smelting and working of iron amongst the eastern Slavs (Gayvoron) during the 6th and 7th centuries and the later periods AD.
CPSA

J Ziomecki. **Representations of artisans on Attic vases.** Wroclaw – Warszawa – Gdansk *1975. (In French).*

This monograph gives a list of iconographic sources representing various crafts of the period between 520–460 BC. Scenes depicting smiths and metallurgical topics relate mostly to the Hephaestus myth.
CPSA

V Souchopova. **A village of the 10th century AD at Boritov.** Archaeologia Historica I. Brno, *1976, 153–157. (In Czech).*

Sunken-floored huts, one of which contained a considerable quantity of smithing cinder. The presumed affinity to the iron smelting centre near Olomoucany (western Moravia) seems to be evident. The site lies on an important south-north-route.
CPSA

S Vencl, N. Venclova and J Zadak. **A settlement of the Roman period in the vicinity of Dubeč.** Archeologicke rozhledy *1976,* 28, *247–276 (In Czech).*

A bloomery of the early Roman period was found at Dubeč near Prague. The sunken workshop (about 5 m in diameter) contained at least 7 furnaces with slag pits. Analysis of slags was carried out by R Pleiner. Several settlements were found alongside a brook and the bloomery belongs to one of these.
CPSA

H Geisler. **A hoard of Late Roman Ironwork from Breslack, Eisenhüttenstadt.** Veröffentlichungen des Museums für Ur– und Frühgeschichte, Potsdam, *1976,* **10**, *141–158. (In German).*

The hoard was buried in a sunken-floored hut consisting of 17 objects, 15 of which were of iron (axes, knives, rods, sheet, spear etc) and can be dated to the period AD 250–400. An iron coulter and a spear were found in the filling near the hoard.
CPSA

AFRICA

F Willett and S J Fleming. **A catalogue of important Nigerian copper-alloy castings dated by thermoluminescence.** Archaeometry, *1976,* 18 *(2), 135–146.*

Dating of the casting cores from several copper castings from Ife (including the Lafogido figure from Wunmonije Compound), Benin and Tada is reported and, in each case, a comparison made with current age estimates based on stylistic criteria.

Thurstan Shaw. **Those Igbo-Ukwu Radiocarbon dates: Facts, Fictions and Probabilities.** Journal of African History, *1975,* 16 *(4), 503–517.*

In the discussion of the reliance which should be placed on the Igbo-Ukwu radiocarbon dates, it is necessary to make certain that what evidence we have is correctly used. The precise locations of the samples used for dating are recalled and possible sources of error discussed. Consideration is given to the arguments for a later date than that suggested by the radiocarbon dates, stemming from the state of preservation of the textiles, the character of the beads, the pottery evidence, analogies with the presumed dating of Ife and Benin, the quantity and the source of copper, and what is known of the pre-European trading patterns in West Africa. The latter is probably the most serious objection to a very early date, but the question will only be settled with the acquisition of more archaeological evidence.

(Author's summary)

L M Pole. **Iron-working apparatus and techniques: Upper Region of Ghana.** West African Journal of Archaeology, *1975,* 5, *11–39.*

Indigenous methods of iron smelting were investigated in ten localities in the extreme north of Ghana, wherever possible by having a traditional type of furnace constructed and a smelt carried out. Individual differences are described, but in general the furnaces conform to a cylindrical type about 150 cm high, usually inclined at a small angle, with an internal diameter of not more than 30 cm, yielding between 2.0 and 3.5 kg of iron per smelt. Methods of smithing are also described.

ECJT

L M Pole. **Account of an iron-smelting operation at Lawra, Upper Region.** Ghana Journal of Science, *October 1974,* 14 *(2), 127–136.*

A detailed, timed description is given of an iron-smelting operation as observed in the blacksmiths' area of Lawra, North-west of Upper Region, Ghana, in March 1972. This process has not been used in this part of the country for over 30 years and is now only rarely done anywhere in West Africa.

ECJT

Hans-Ekkehard Eckert. **Native iron production of the Senufo in West Africa.** Der Anschnitt, *1976,* 28 *(2), 50–63.*

At the southern flanks of the Sahara in the land of the Senufo there are many iron smelters and smiths which form a separate group. Detailed description of bloomery furnaces at the village of Koni which is one of the centres where smelting is carried out according to old tradition. 200 of the 1200 inhabitants are iron-workers. At the end of Koni there are 13 furnaces, 15 storage huts and one smithy. The mines are 5 km west of Koni. Processes described.

ECJT

A R Williams and K R Maxwell-Hyslop. **Ancient steel from Egypt.** Journ. Arch. Science, *1976,* 3, *283–305.*

Three of the specimens examined consisted of wrought iron with appreciable amounts of slag included. Two of the other specimens had been case-carburized along their cutting edges after fabrication and then quenched. The fairly low carbon contents (0.1–0.2% C) resulted in only moderate but worthwhile (threefold) gains in hardness, and brittleness was unlikely to have become a problem. Two of the specimens consisted of fairly homogeneous steels (c 0.2% C) which had also been quenched to harden them. The visible forging lines in one of the specimen (and the symmetrical carbon gradient shown) suggests that these tools were also made by case-carburizing before fabrication, perhaps followed by folding the bar double.

ASIA

B Rothenberg. **Metals and Metallurgy.** In Investigations at Lachish; Lachish V, University of Tel-Aviv, *1975, Chapter 12, 12 pp, 3 Pl.*

Describes the copper-base alloys and iron finds. Gives analyses of copper-base metals and iron and copper slags. Includes some tuyere ends. No metallography. This group gives a typical view of Iron Age II metallurgy in Palestine with emphasis on iron as metal for tools, and continued use of copper-base metals wherever technology or economics could make this appropriate.

RFT

E R Eaton and H McKerrell. **Near Eastern alloying and some textual evidence for the early use of arsenical copper.** World Archaeology, *October 1976,* 8 *(2), 169–191.*

The analytical background to the textual translations of words for ancient metals is considered in the light of all previously published analytical data and of several thousand new results. The possibility of alternatives to the usual translations of the metals Egyptian **d(m**, Greek **oreichalkos** and Akkadian **annaku** are discussed in the light of the analytical evidence.

H Limet. **The origin of iron work in early Mesopotamia.** Revue bimestrielle de l'Association royale des ingenieurs commerciaux, licenciés et docteurs de Mons-Warcoque, *1976 (92), 3–16.*

The author of 'Le travail du métal au pays de Sumer' (Paris 1960), presents a concise survey of the most ancient lexicographical sources of the Near East containing the terms related to 'iron'. He suggests the lexical development of this word to have taken place in the period about 2000 BC.

CPSA

N K Sandars. **Thracians, Phrygians and Iron.** Thracia III. Primus Congressus studiorum Thracicorum. *Serdicae, 1974 (Sofia 1975).*

Since the Bosphorus was not a strict natural frontier the Phrygian tribes (in the author's opinion include the tribes of Mushki and Tabal from Asia Minor) acted as intermediaries in the transmission of knowledge of iron technology from Anatolia directly to Macedonia and Thracia.

D Chakrabarti: **The beginning of iron in India.** Antiquity, *1976,* 50 *(198), 114–124.*

The author sees the coincidence between the rapid social development in India after 800 BC and the introduction of iron. Relying on some 14C data of the Malwa Culture in Central India and from the South (Hallur) he suggests that this part of the Subcontinent was an independent birthplace of iron technology. No impact from the West or Northwest seems to be probable in his eyes. However, the use of iron in agriculture according to the Taittiriya Samhita 5.2.5. may be a very free interpretation of the text.

CPSA

D A Khakhutaishvili. **A contribution of the Cartevlian Tribes to the mastery of iron metallurgy in the ancient Near East.** Acta Antiqua Academiae Scientiarum Hungaricae, *1974,* 22, *337–348.*

Preliminary report on discoveries of early bloomery sites in ancient Kolchis, the present West Georgia, USSR, bringing in some documentary material but treating the digs as a whole without giving the names of individual localities. Suggested dating: the 9th cent. BC. The author believes that the iron was exploited on behalf of Assyria and Urartu.

T S Wheeler and R Maddin. **The techniques of early Thai metalsmiths.** Expedition, *1975–76,* 18, *37–47.*

Discusses the composition and structure of mostly copper-base alloy finds from Non Nok Tha and Ban Chiang which date from 3600 BC to 1 BC. The structures show tin bronzes with 1.3 to 25% tin and brasses with more than 10% Zn. The lead contents were within the range 1 to 5% and some of the objects had been finally cold worked.

One object from Ban Chiang was a bimetallic (iron + bronze) spearhead dated to 1600–1300 BC. The iron blade is totally rusted but the Ni content is lower than that expected for meteoric iron. RFT

Ursula M Franklin, J–C Grosjean and M J Tinkler. **A study of ancient slags from Oman, Iran. Canadian Metallurgical** Quarterly, *1976* 15 *(1), 29–35.*

Microscopic, chemical and X-ray techniques were used to examine slags from an extensive ancient mining site in the Persian Gulf area. The experimental results indicated that the samples were pieces of tap slag and furnace slag from the production of copper matte. Such copper mattes could have been smelted in furnaces similar to those used during the Roman period in Timna, Israel.

Author's abstract.

Hans-Gert Bachmann. **Metallurgical researches on the south coast of the Black Sea, Turkey.** Der Anschnitt, *1976,* 28 *(1), 14–24.*

A reassessment of ancient literary sources; an account of the 19th century geographer and geologist W J Hamilton and the author's personal visit to the area is given. New investigations and excavations of the area are needed. The author is in no doubt that mining and metallurgy was carried on from a very early date as the evidence shows. ECJT

Techniques

A Mazur and Z Mazur. **Modern observation of the structure of ancient iron finds by means of the transmission electron and and optical microscopy.** *(In Polish).* Archeologia Polski (Metody.), *1976,* **21,** *11–37.*

Three types of finds were taken for observation by means of a transmission electron microscope because of their different degree of plastic deformation – an important factor in interpretation. The structure of a steel billet (0.7%C) of the Lusatian culture was analysed. The small copper content indicates that the billet has been imported from West Europe. The sample had a small degree of plastic deformation. For comparison, an iron shield-spike of the late Roman period was taken. This find has a high degree of plastic deformation. The third group examined were Roman iron nails from Inchtuthil, Scotland. These represented various stages of plastic deformation. The experiments were aimed at observing long-lasting aging effects at low temperatures which might help to throw light on ancient technology. ECJT

B G Scott. **A note on the application of X radiography in the conservation and study of archaeological ironwork.** Irish Archaeological Research Forum, *1976, III (1), 1–8.*

Examples of iron artifacts from Clogher, Co. Tyrone, and from Greencastle, Co. Don. Adapted radiography unit from a hospital. Parameters to all X-ray plates added. CPSA

B Bevan. **A magnetic survey at Les Forges du Saint-Maurice.** MASCA–Newsletter, *Dec 1975,* **11** *(2), 1.*

The campaign concerned in industrial site of the 18th up to the 19th century, AD. Describes the successful use of a caesium magnetometer for prospection of iron working features. CPSA

J B Lambert and C D McLaughlin. **X-ray photoelectron spectroscopy: A new analytical method for the examination of archaeological artefacts,** Archaeometry, *1976,* 18 *(2), 169–180.*

X-ray photoelectron spectroscopy (XPS) provides a new method for the analysis of artifact composition. This technique identifies elements by the characteristic energies of electrons that are ejected by bombardment of the sample with X-rays. All elements except hydrogen can be analysed simultaneously on recoverable mg samples. Electron binding energies for a given element differ slightly according to its chemical constitution, so that exidation states and other chemical information can be obtained. To illustrate the utility of XPS in qualitative analysis, we present data on glass, pottery, metal, bone, and stone artifacts or materials. The oxidation state of the copper colourant in a turquoise-blue Egyptian glass fragment is proved to be Cu^{2+}, whereas that of copper in red glasses is proved to be Cu^0 or Cu^+. Integration of XPS peaks can provide quantitative analysis by comparison with accurate standards. We have carried out a semiquantitative analysis of Kherbat Kerak pottery by determination of the relative proportions of elements without the use of standards. Pattern analysis of these data shows distinct compositional characteristics for different excavation sites.

M J Hughes, M R Cowell and P T Craddock. **Atomic absorption techniques in archaeology.** Archaeometry, *1976,* 18 *(1), 19–37.*

Atomic absorption spectrometry is a useful technique for the analysis of both major elements and trace elements in archaeological objects. The technique provides accurate analyses of the internal composition of an object based on c. 10 mg samples of material drilled or abraded from the object. Systematic schemes of analysis have been developed and are described for ancient metals and silicate-based materials which take account of the special problems encountered in the analysis of archaeological specimens. One operator can analyse over 200 bronze objects for 10 elements within 5 days. Among recent developments in atomic absorption is flameless atomization and examples are given of its applicability to trace elements present at the parts per million level in objects which are of use in tracing the provenance of object, for example.

M de Bruin, P J M Korthoven, A J v.d. Steen, J P W Houtman and R P W Duin. **The use of trace element concentrations in the identification of objects.** Archaeometry, *1976,* 18 *(1), 75–83.*

Trace element concentrations are presently used for the identification of samples of a large variety of materials. When applying such a procedure, many problems may be encountered, especially with respect to sample preparation and interpretation of the analysis results. Moreover, the results of the identification procedure have to be interpreted with sufficient restrictions.

R J Fleet. The application of specific heat in the detection of debasement in ancient silver/copper alloy coins. Archaeometry, *1976*, 18 *(1), 117–120.*

The silver content was calculated for ancient coins using the specific-heat method. The Roman debasement of circa AD 193 was clearly shown, and the usefulness of the technique in non-destructive analysis established. Comparison with the density method confirmed that the latter was unsuitable.

Mancini C and P P Serafin. **Identification of ancient silver-plated coins by means of neutron absorption.** Archaeometry, *1976*, 18 *(1), 117–120.*

This paper deals with a non-destructive method (neutron absorption) for the identification of ancient silver-plated coins. The experimental equipment, easily transportable, makes use of a 1 μg^{252} Cf neutron source. Results of measurements performed at the National Museum of Naples are reported.

Karl Roesch & Hans Martin Kühn. Synthetic manufacture of bloomery iron and its handicraft processing. Archiv f.d. Eisenhüttenwesen, *1976*, 47 *(1), 5–8.*

Manufacture of iron blooms by annealing charcoal encased low-phosphorus and high-phosphorus ores in a continuous gas annealing furnace. Comparison of the metallurgical processes observed with the results of African bloomery furnaces obtained during exploring expeditions and with former investigations on the reduction of iron in the bloomery. The predominant role of phosphorus. Carbonization of the iron blooms obtained to steel. Only those pieces of the blooms obtained to steel. Only those pieces of the blooms manufactured synthetically which were made from low-phosphorus iron ore could be forged out.

Author's abstract

Note

One of our members, Monsieur Jean Maréchal of France, reports that the French are starting a Comité d'Etudes Archeometallurqique under the aegis of Professor R Chevallier and hope to undertake new laboratory experiments on such things as the addition of arsenic to copper and the globularisation of minerals enriched in silver or copper.

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