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Sir William Siemens 1823 - 1883

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The cover illustration is of **Sir William Siemens** who died one hundred years ago last November, and who made a momentous contribution to both ferrous and non-ferrous metallurgy.

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Ancient Athenian silver mines, dressing floors and smelting sites

John Ellis Jones

Abstract

The article briefly surveys the geology of southern Attica and the technology of the ancient silver mines, from actual mining through to smelting, and concludes with some remarks on the history of the industry. It describes the principal types of site, with reference to the most important examples excavated in recent years; several of these are illustrated by plans, reconstruction sketches and photographs. It draws on recent publications and the author's autopsy of sites and his own excavations. Analyses of specimens of typical slags are contributed by Dr N H Gale.

The famous silver mines of the ancient city-state of Athens were located in the south-east part of the Attic peninsula, in the hilly Laurion district (Fig 1). During the modern revival of mining there, in the last century, there arose on the coast a new town to serve as industrial centre and port, which was called at first simply Ergastiri ('Workshops'), but eventually dignified with the transferred classical name of Laurion. In antiquity a similar role was played by Thorikos, a coastal city venerable for its religious and legendary associations; it became so closely linked to the fortunes of the local industry as to grow into a boom town in the 5th and 4th centuries BC and decline into a ghost town by the 1st AD. In the hills and glens of the interior there were many other mining villages and townships, heavily populated while the mines were active. Classical literature and archaeological remains testify to the scale of the industry and its importance for the rise of Athens to imperial power. Recent researches have thrown new light on the history and technology of the classical mines and hint at the metallurgical importance of the area in still earlier times.[1]

I. Geology

The geological make-up of the Laurion area can be very simply summarized (Fig 2). There are five main geological strata, composed of alternate layers of whitish calciferous rocks (limestones and marble) and of micaschists (grey-green in colour, with a micaceous lustre). There are three layers of limestone, with two layers of schist in between. These rock layers had different degrees of 'porosity', schist being rather impervious, limestone more porous, and offering less resistance to the upward thrust of hot mineral-rich 'liquids' from the earth's depths. These liquids therefore tended to pass through the limestone and spread out at the contact level between limestone and schists. The so-called first contact and third contact levels were the richest ore-bearing levels, and the most profitable to mine.

Argentiferous lead ores were found mainly in the first contact and the third, in the first often as oxidized lead ore or cerussite ($PbCO_3$) and in the third contact mainly as galena (very argentiferous, being about 1200-1400 grams of silver to 1 ton of ore). Early mining probably exploited the first contact, closest to the surface, while the third contact levels were tapped later when deeper prospecting was done. Possibly the great new 'found of silver' recorded as found c 484 BC in the Laurion may have been a new exploitation of the third contact (the profit paid for the new Athenian fleet which defeated the invading Persians in 480 BC). Various minor or trace quantities of other metal ores exist

Fig 1 *Maps of Greece, Attica, the Thorikos plain and south-east Attica; sites in capitals, modern places in lower case letters; symbols distinguish dressing floors and furnace sites.*

in the lead ore layers, such as copper, iron, zinc and manganese. The copper and iron were both exploited to some extent by the Greeks in antiquity, but not the zinc and manganese. Two of these trace ores had an incidental use for the ancient prospector: the iron ore caused a rusty discoloration where it outcropped on the surface and so served as a useful 'marker' for the contact layer, as did the manganese with its dark staining. Examples can be seen at Thorikos: a line of ochreous boulders along the lower reaches of the Industrial Quarter of the town, and the contrast between the white limestone above the mine gallery near the ancient theatre and the black-stained rock sloping down to its entrance.

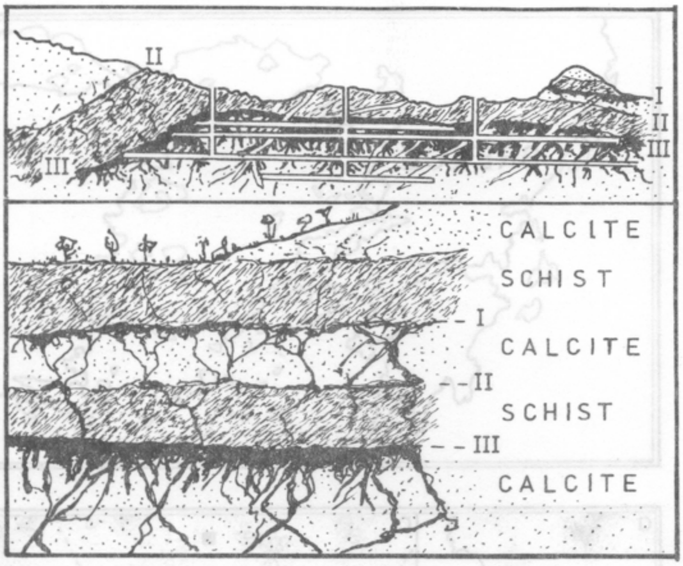


Fig 2 *The geology of the Laurion area; a schematic cross-section showing the alternating layers of calcite and schists and the contact levels.*

II. Mining

The easiest approach was by cutting in horizontally from the surface at the contact level, where changes in rock formation and the marker staining of ochre-red 'sideropetra' (iron stone) or dark manganese acted as pointers. Such levels or adits and also open-cast pits were used from early times, and there are plenty of examples of open-cast mines and open pits and level adits in the Laurion hills. Good examples of adits can be seen at Thorikos where a modern quarry has cut the hillside back, forming a 'giant archaeological section' which now shows the approximately horizontal crack-line between the natural rock levels and a series of galleries running into the hill just on and above that line, the contact level (Fig 3).

These galleries vary in shape; sometimes a gallery is cut very economically – only about 0.70 m wide x 1.00 m high, and shaped as shown in Fig 4. But in places the galleries open out into considerable chambers where the miners extracted all the ore which sometimes had filled considerable crevices between the rock strata – ie where a thin vein of ore swelled out into a large 'bubble'. Where these chambers were quite large, a 'column' of natural rock (or ore) was left to support the roof here and there, or the quarried stone spoil might be built up into supporting walls. Of course, not all the spoil was carried out of the mine – to save effort one tried to cut and carry out only worthwhile ore, and so there would be a rough sorting over of the lumps of rock and ore at the mine-face, and then the ore was piled into baskets to be carried outside.

For contact layers deeper down under the surface, vertical shafts might have to be cut as a preliminary approach, and then galleries would branch out horizontally once the ore contact level was reached. Again, vertical shafts might be used for ventilation, when adits cut from the surface slopes of a hill had reached so far underground that air would not reach the working face unless vertical shafts were cut (like 'chimneys'), to create draughts. Many such pits are known in the Laurion area. Sometimes they are cut very neatly and are square or rectangular, sometimes only about 1 metre

Fig 3 *Ancient Thorikos: the face of a modern quarry on the lower slopes of the hill, with a row of ancient galleries on the contact level showing in section.*

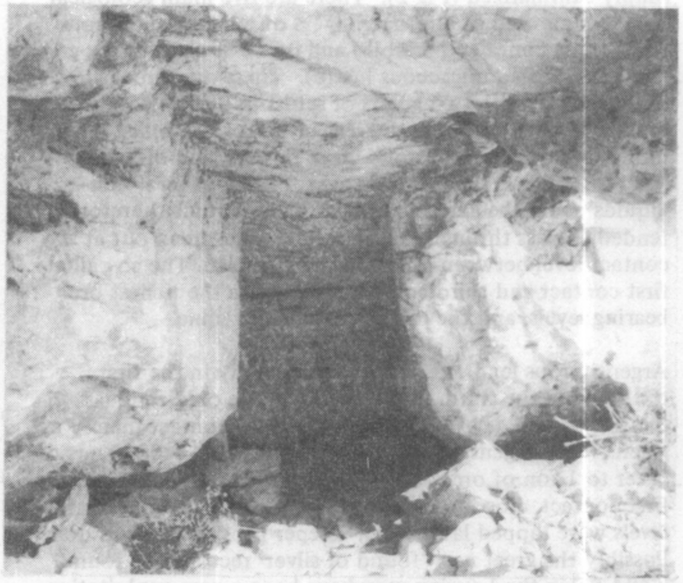


Fig 4 *Ancient Thorikos: a close-up view in the modern quarry, showing one of the low narrow galleries.*

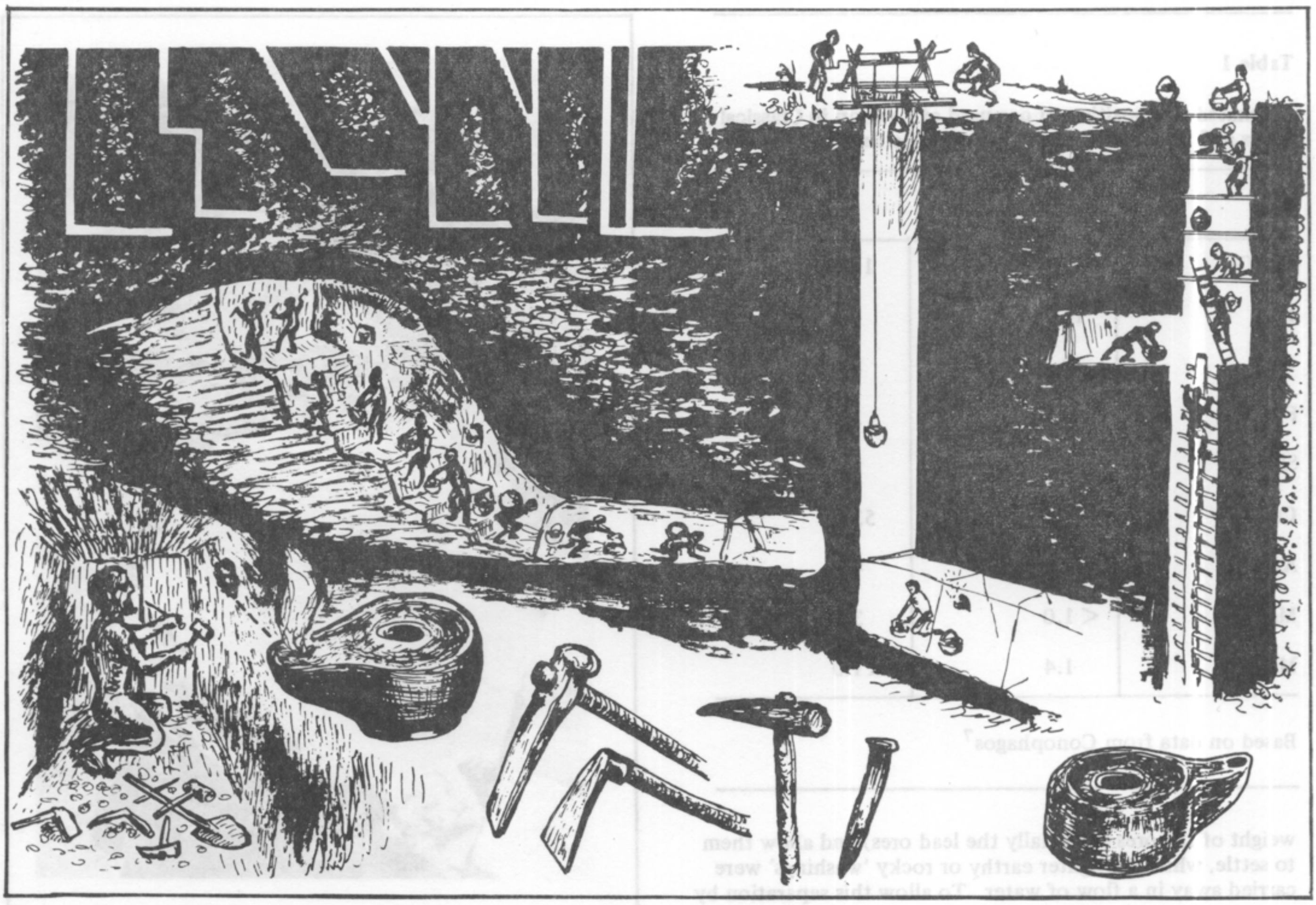


Fig 5 The Laurion mines: schematic sections and sketches of ancient shafts and galleries illustrating the variety of form, and a sketch of a miner at work, with close-up views of his tools and lamp.

square, with hand-and-foot holds cut in the sides, or holes at longer intervals for attachment of vertical wooden ladders. Sometimes the surface hole is less regular due to the friable nature of the surface rock. A number of sloping shafts have also been found, which then level out at the ore contact levels; in some cases the descent is stepped. Ore would be taken out of the mines either back along the galleries or up extraction pit-shafts, or up the steps of the sloping shafts (Fig 5).

The ancient miners in the Laurion were mainly slaves. They used a limited range of hand tools: hammer (tupis), 20-30 cms long, with iron head, pointed at one end, flat the other, and tough olive-wood handle; chisel (xois) of iron for use with hammer (cf the rock-cut carving of Archidamos of Thera using hammer and chisel, on the side of the Cave of Pan, at Vari in SW Attica); pick, with iron head or blade, generally single-ended, 40 cms long x about 15 cms wide, with a point at one end and a socket at the other for a wooden handle; mattock/shovel (skalis) for raking up the ore and debris (something like the modern Greek scraper shovel, set vertically from the handle). To carry the ore, miners would also use leather sacks or baskets of woven grass (like the modern 'zembilia' used till recently in excavations).

For lighting they had torches and oil-lamps. Possibly the rather deep 'ink-well' form of lamp so common at Thorikos (and uncommon in the Agora and other excavation sites in Athens and Attica) may well be a type developed for the locality — with a long-lasting supply of oil, to last a whole work-shift.

III. Processing of Ore: Sorting and Milling

After a preliminary sorting of the lumps of ore at the mine-face, a secondary sorting was done outside, near the pit-head or the gallery mouth, again to remove lumps of rocky spoil which had little or no percentage of ore. The ores were various, but the commonest, most profitable ore was galena (lead glance, lead sulphide, PbS) a heavy, grey, sometimes rather shiny and crystalline ore found in rich quantities in the deep, third contact levels; it was associated with silver ores, and frequently itself contained native silver. Other lead ores were cerussite (lead carbonate, $Pb\,CO_3$), formed by action of carbonated waters on galena, and anglesite (a lead sulphate, $PbSO_4$). Silver was found both as native (natural metallic state) silver and as ores, especially as argentite or silver sulphide (Ag_2S) which is often associated with galena (lead sulphide). Cerargyrite or 'horn silver' (silver chloride, $AgCl$), was also found with native silver and cerussite. In the Laurion area a considerable amount of zinc ore or sphalerite (zinc sulphide, ZnS) was often found along with galena, and small quantities of iron and manganese ores (traces only). A typical analysis is given in Table 1.

Before smelting, to save fuel and avoid having too much useless slag, it was necessary to purify or concentrate the ore. This was done by washing it so as to exploit the heavier

Table 1

Estimated composition of ore used at Laurion in Classical times and the dressed ore charged to the furnaces

	% charge (concentrate)	Mined ore
$PbCO_3$	65)	16.0)
	) 72.3% Pb	) 17.5% Pb
Pb S	15)	4.0)
Zns	8	8.0
Fe_2O_3	4.55	3.0
SiO_2	5.34	2.5
$CaCO_3$	2.66	53.0
Al_2O_3	< 1.0	4.0
MgO	< 1.0	3.5
MnO	1.4	<1.0

Based on data from Conophagos[7]

weight of the ores (especially the lead ores) and allow them to settle, while the lighter earthy or rocky 'washings' were carried away in a flow of water. To allow this separation by weight in water, it was necessary to pound and mill the crude ore as finely as possible, so that the current could separate the fine grains of ore, stone and earth.

The first stage was to pound or break the large lumps of ore into smaller pieces by hammering it with iron mallets on a 'chopping-block', generally a large, fairly flat-topped boulder. Probably the commonest such 'blocks' were limestone boulders – after all, such were the commonest boulders in the area! Examples are to be seen at Thorikos, in the south annexe room next to Washery No 1, in the Industrial Quarter (Fig 6), and at Agrileza, in the south court alongside Washery C. Sometimes an iron-ore impregnated limestone boulder (ie the ochre-yellow 'sidero-petra' or 'ironstone') might be used, as that was particularly tough and difficult to split; an example is known at Agrileza, alongside the modern track near Washery B. These pounding-blocks are generally recognizable because the upper surface is worn smooth, and indeed hollowed by long use.

The next stage was to grind the now-broken ore fragments into a fine sandy consistency (rather like granulated sugar). This was done in hard stone mills of various kinds (Fig 7). A lava stone from the volcanic island of Thera (Santorini) was often used to make mill stones; it was dark grey, very hard stone, sometimes with a rather 'porous' appearance, like petrified sponges. Deeper stone mortars were also used, with pestles to break up the ore further.

One form of mill was the 'hour glass' type, which had a high stone 'ring' fitted down onto a central cone-shaped stone 'spindle'; the open funnel-shaped top of the ring would hold the ore, and as the ring was rotated round the 'spindle', the ore would fall down between the two stones and be ground down finer. A good, partial example of this type is the fixed upright cone spindle which was found at Thorikos, again in the south annexe room of Washery No 1 (Fig 8). (Such 'hour-glass' mills were widely used to grind corn also, as at Pompeii up to 79 AD).

Fig 6 *Ancient Thorikos: a limestone boulder hollowed by use as a pounding block in a room near Washery No 1. The dark stone behind is the spindle of a rotary mill. Their position is shown in Fig 8.*

Another type of grinder was the hopper-quern. This was formed of two rectangular stones; the top one had a deep hopper cut into it, with a slit at the bottom, and the lower was a larger, flatter slab, like a thick stone 'bread-board'. The ore was filled into the hopper and as the top stone was moved from side to side, grain would fall through the slit, and onto the corrugated top of the slab below, and then it was crushed into fine sand between the grooved underside of the hopper and grooved topside of the lower stone. (Such hopper querns were used also to mill corn, as at Olynthus in northern Greece, in the 5th and 4th centuries BC). Hopper querns varied in size, but many hoppers measured about 40 x 60 cms, and stood about 15 cms high.

IV. Ore Washing

The next stage of ore-processing was to wash the fine-milled ore in a flow of water, so that the heavier grains of ore and the lighter grains of stone and earth were separated. In that way the ore could be cleaned and concentrated, and made ready for smelting. The process of separation and grading by sheer weight of the purer lead (and silver) ore is an old

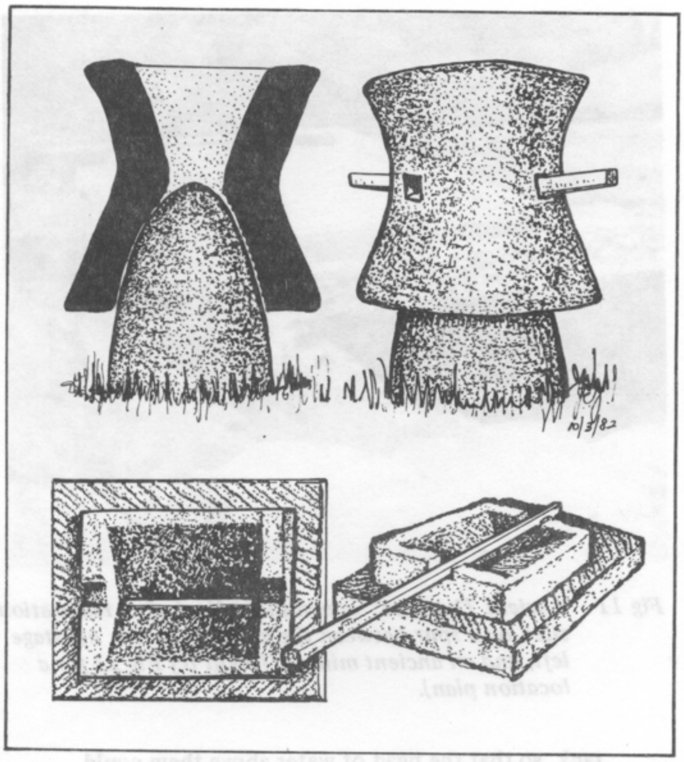


Fig 7 A rotary mill and a hopper quern of the types used for grinding ore to a size fine enough to wash.

one (cf gold-panning) and is still used (as it was in old Welsh lead mines). But the problem was that the water-supply was so very scarce in the largely rainless Laurion area. The sparse, seasonal rainwater had to be collected and conserved in large round or rectangular cisterns, and rationed out for use all the year round.[2] Further, some method had to be devised to save and re-use the water. So in the classical period there were developed some ingenious washing-tables which allowed circulation and re-use of the water, and these were used in conjunction with the large cisterns. The cisterns generally had filter or clarification basins to remove scum and silt from the surface water before it flowed through into the main reservoirs; the latter were round or rectangular in shape, and originally roofed to prevent the standing water from turning green and murky and to reduce evaporation (Fig 9).

There were two main types of washing tables or washeries ('plungeria' in Greek). The most common by far was the level rectangular type which could vary considerably in plan; these variations probably reflected improvements worked out over a long period of development. The other was the rare and perhaps late type, the circular or helicoidal (spiral) washery of which only three examples are known.

(i) Rectangular Washeries

The rectangular washing-tables were surfaced with a hard hydraulic cement which has often survived remarkably well. So they impress as the most easily recognizable remains of the ancient surface-works, sometimes being only thinly covered with loose rubble, silted earth and pine-needles; several have been cleared or part-cleared, and two have been restored. At ancient Thorikos two excellently renovated examples are on view (Figs 10, 11) in Washery No 1, which is part of a works-compound in the Industrial Quarter, and in Washery No 4, sited between the theatre and a mine gallery (with yet another washery of earlier date and less regular plan just beyond that). Near the modern hamlet of Thorikos, washeries have been investigated on both slopes of a rocky knoll behind the Belplast factory. In the Laurion hills others have been uncovered at a site called Soureza, at the head of the Agrileza valley, and a fine example lower down, in the valley bottom at the foot of Mt Michaeli (Fig 12). Further down-valley but on the open hillside, a site called Agrileza has revealed three more washeries (A, B, C) of which one (A) resembles the two restored Thorikos examples in size and plan, but the third (C) is the largest washery in the whole area excavated to date.

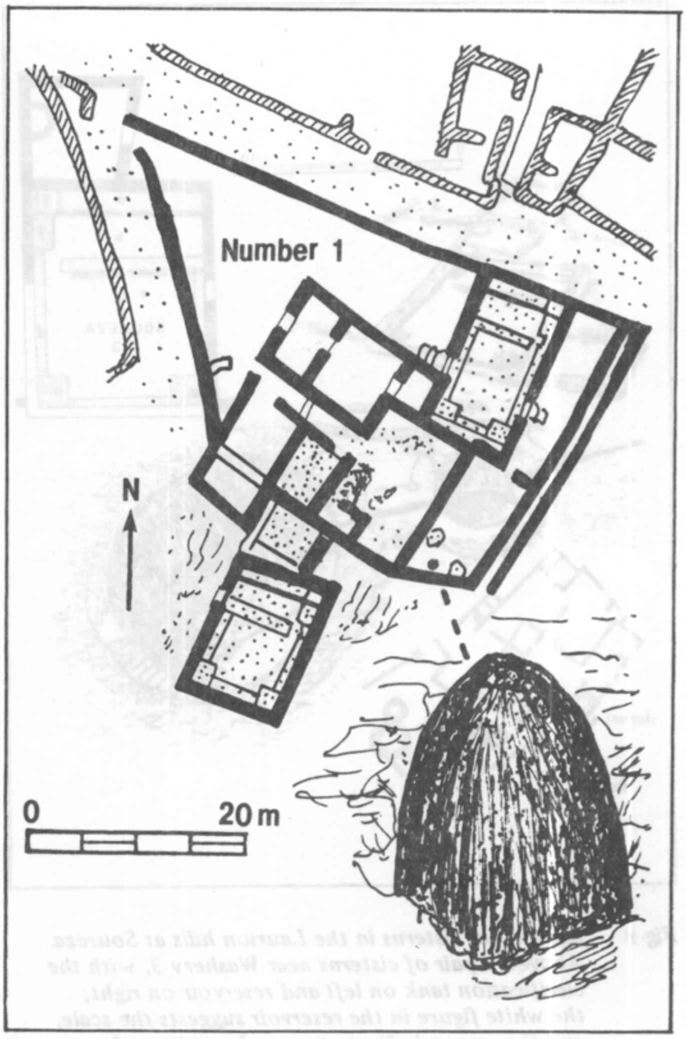


Fig 8 Ancient Thorikos: a plan of the works-compound of Washery No 1, showing the location of its grindery with its pounding blocks and the surviving part of a rotary mill.

These examples have the following common elements (Fig 13):

(a) a transverse stand-tank, generally 0.80-1.00m wide and up to 1.00m high, with from three (eg Agrileza A), to four or more (uniquely, seven in Agrileza C), funnel-shaped holes in the front face (Fig 14). That front wall was usually made of thin limestone slabs set on edge in a row and plaster-faced, and only c0.15m thick (and therefore often found much damaged, with the slabs broken or uprooted). Sometimes a rubble-built front wall was used, c0.30m thick. The funnel-holes were generally about half-way up the face of the

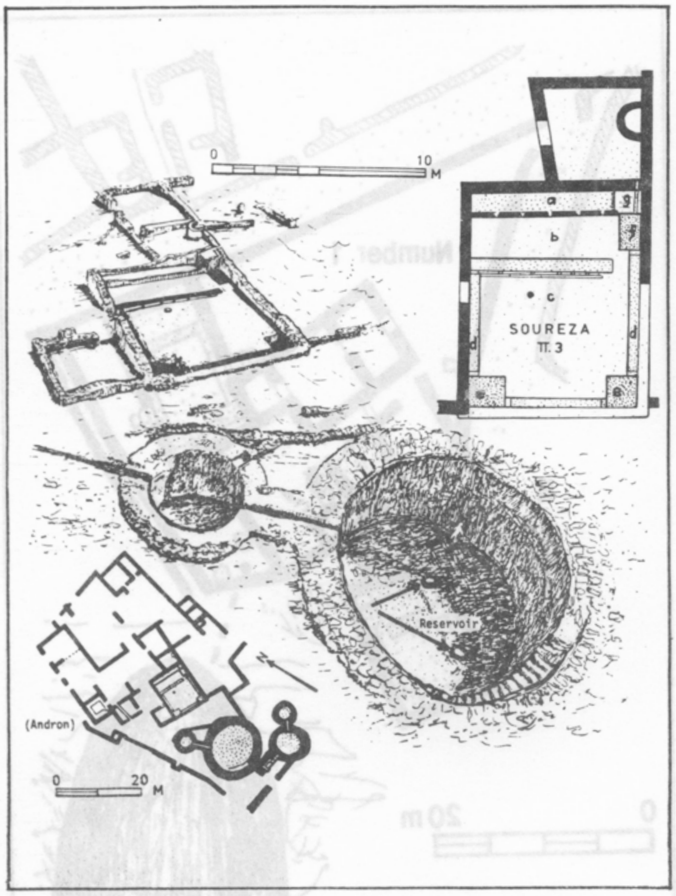


Fig 9 *Rain-water cisterns in the Laurion hills at Soureza. Above: a pair of cisterns near Washery 3, with the clarification tank on left and reservoir on right; the white figure in the reservoir suggests the scale, and the arrows indicate two rock-cut bases for stone columns which propped up a roof like a lid over the water. Below: the plan of the whole works-compound showing the same two cisterns and another pair.*

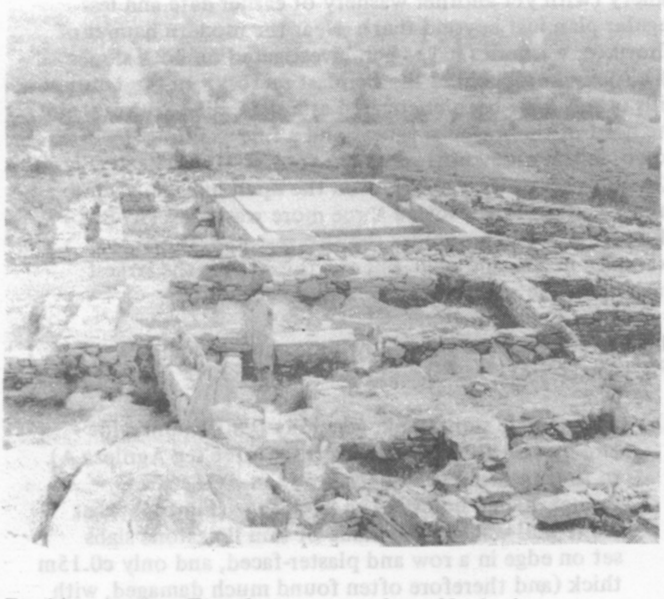


Fig 10 *Ancient Thorikos: ore-washery No 1 after restoration, viewed from the hillside, looking north-west.*

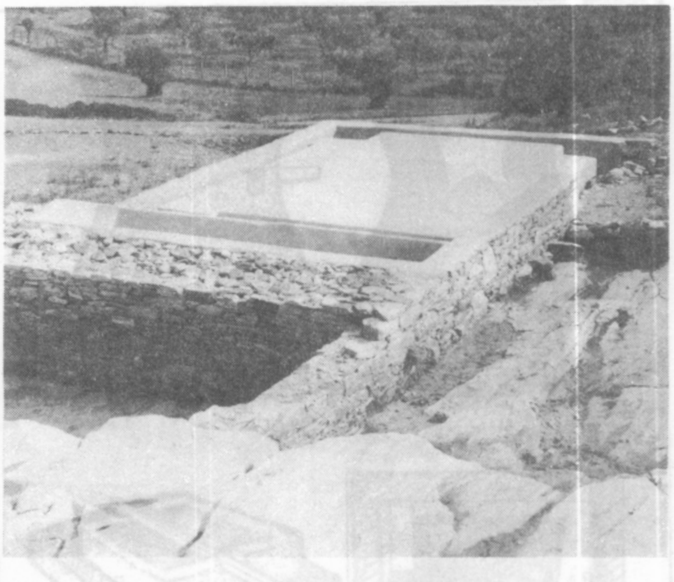


Fig 11 *Ancient Thorikos: ore-washery No 4 after restoration, sited on a spur between the ancient theatre, off-stage left, and an ancient mine, off right (cf Fig 23 for a location plan).*

tank, so that the head of water above them could force the water to jet out towards –

(b) a washing floor, set in front of the tank. This was generally as long as the tank, extended about 2.0 m forward from its foot, and was surfaced with impervious hydraulic cement, as was –

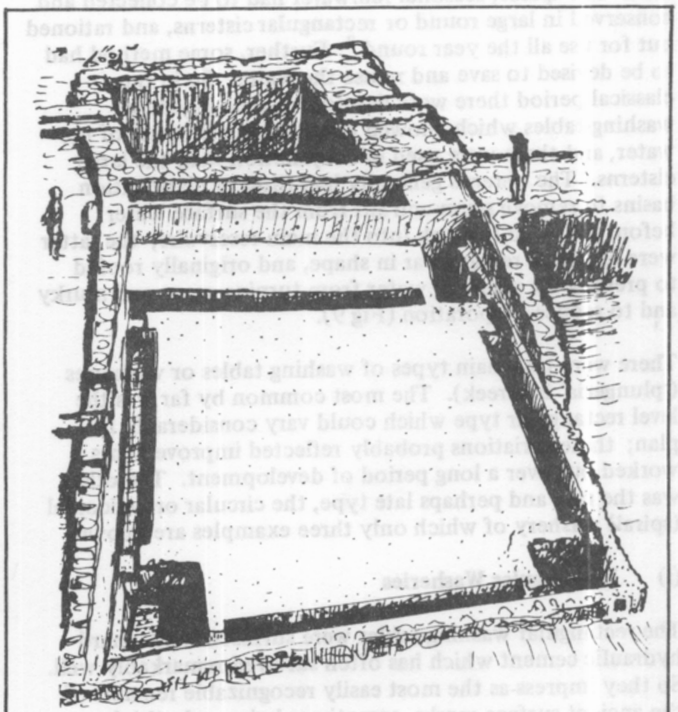


Fig 12 *Sketch of an ore-washery between Soureza and Agrileza, at the foot of Mt Michaeli.*

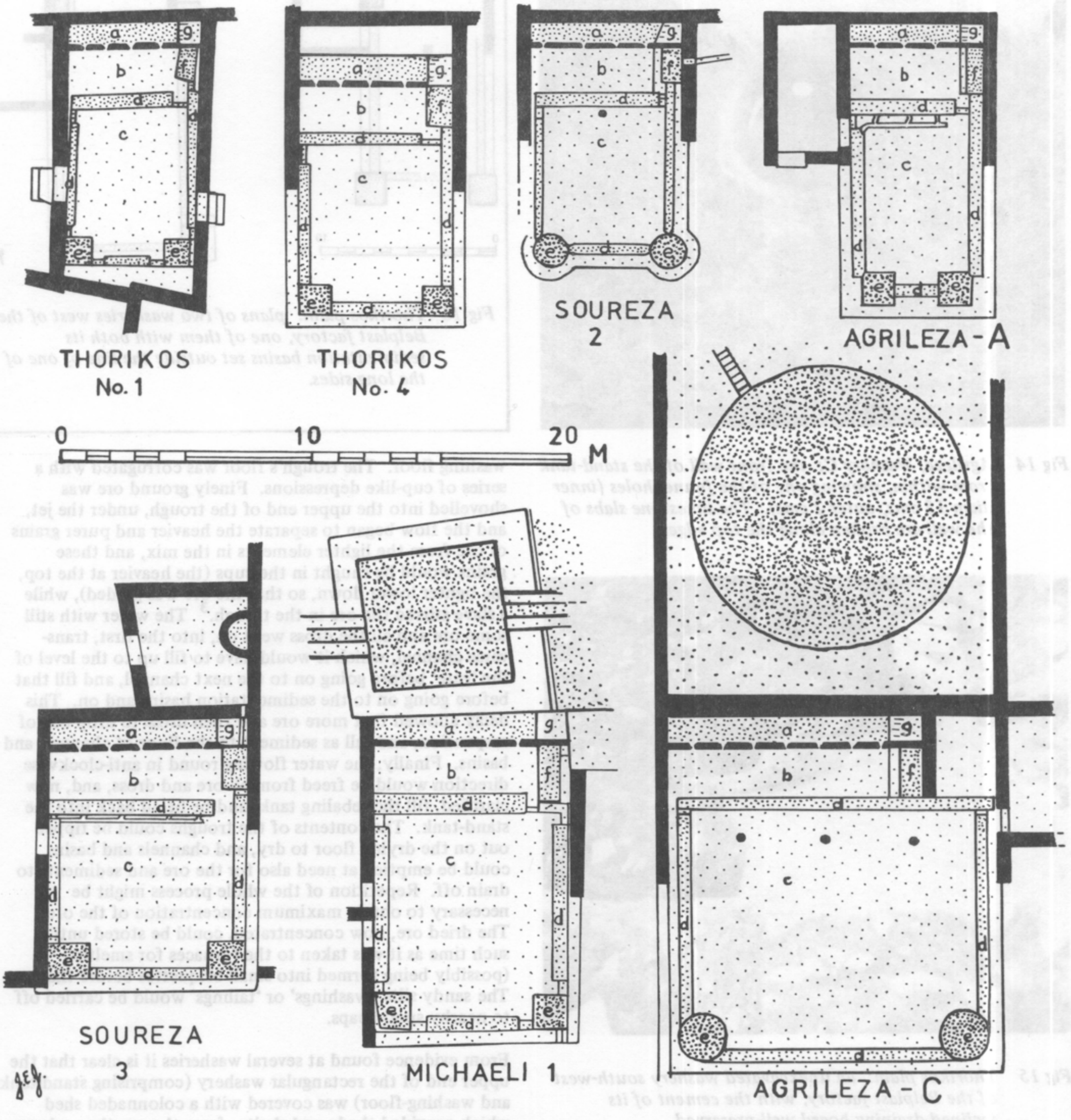
(c) the drying floor, a much larger level rectangular area, which was surrounded by —

(d) four sunken channels, 45-50 cms wide and deep, separated at the corners by a 'gate', a heightened barrier intended to hold back the water in the channel until it rose high enough to flow over the top or through a narrower, limited-flow runnel. The channels linked

(e) deeper sedimentation basins, usually two in number and usually set at the corners furthest from the stand-tank. Their shape was round, square, or rectangular, and their depths varied, but their purpose was the same, to retain quantities of sediment. Beyond these, the water in the channels flowed onwards to —

(f) a deep sunken end-tank, of rectangular shape, termed

Fig 13 Plans of rectangular ore-washeries with the principal features marked: (a) stand-tank; (b) washing floor; (c) drying floor; (c) water channels; (e) sedimentation basins; (f) rebaling tank; (g) draining board. Two washeries (Michaeli I, Agrileza C) have reservoirs immediately behind the stand-tank. Column-bases are preserved at the upper end of drying floors in some cases.



for convenience the rebaling tank. From this the now clarified water was baled in buckets, manually or by means of a bucket on a swivelled beam, back onto –

(g) an inclined-top 'draining board', inset at the end of the stand-tank (Fig 15). So the water seeped back into that tank without disturbing any sediment at the bottom, or causing turbulence. This scheme provided for the recycling of the water, maintained the level of the water in the tank and so kept up the pressure behind the jets.

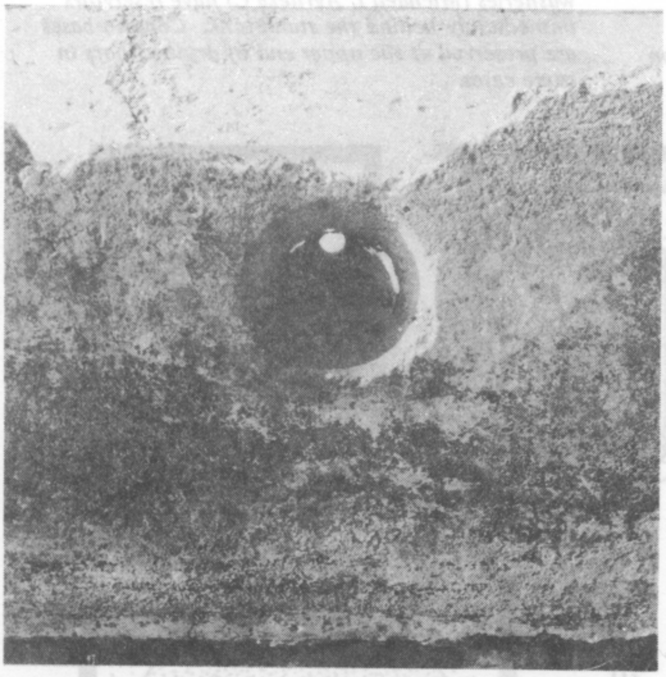


Fig 14 *Agrileza, Washery C: the front wall of the stand-tank from within, showing one of the funnel-holes (inner diam 15 cms, outer 2 cms). The limestone slabs of the wall are broken along the top edges.*

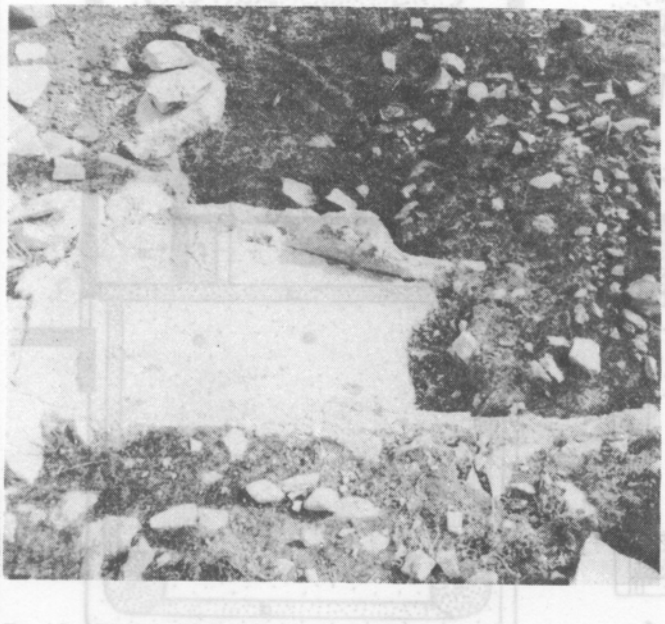


Fig 15 *Thorikos plain: an unexcavated washery south-west of the Belplast factory, with the cement of its inclined draining board well-preserved.*

There are variations in the plan described, such as in the overall size of the washery, or in minor details such as the form of the 'gates' between channels or the shape and relative depth of the sedimentation basins. A more striking variation is seen at one very long washery near modern Thorikos, in the actual location of these basins (Fig 16).

The method of operation at a rectangular washery was as follows (Fig 17). Water was allowed to jet through the funnel holes out of the tank. It flowed into a wooden trough, set at an incline in front of the tank on the washing floor. The trough's floor was corrugated with a series of cup-like depressions. Finely ground ore was shovelled into the upper end of the trough, under the jet, and the flow began to separate the heavier and purer grains of ore from the lighter elements in the mix, and these grains would be caught in the cups (the heavier at the top, the lighter lower down, so that the ore was graded), while a slave stirred the ore in the trough.[3] The water with still some ore and all the dross went on, into the first, transverse channel, which it would have to fill up to the level of the 'gate' before going on to the next channel, and fill that before going on to the sedimentation basins and on. This delay allowed first more ore and then dross to drop out of suspension, and fall as sediment to the floor of channels and basins. Finally, the water flowing round in anti-clockwise direction would be freed from all ore and dross, and, now clarified, fill the rebaling tank, and be lifted back into the stand-tank. The contents of the troughs could be tipped out on the drying floor to dry, and channels and basins could be emptied at need also for the ore and sediments to drain off. Repetition of the whole process might be necessary to obtain maximum concentration of the ore. The dried ore, now concentrated, could be stored until such time as it was taken to the furnaces for smelting (possibly being formed into small briquettes before that). The sandy silts, 'washings' or 'tailings' would be carried off to nearby spoil-heaps.

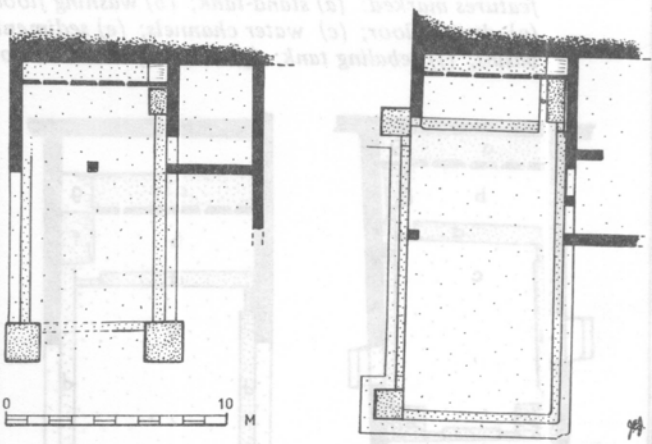


Fig 16 *Thorikos plain: plans of two washeries west of the Belplast factory, one of them with both its sedimentation basins set outside the line of one of the long sides.*

From evidence found at several washeries it is clear that the upper end of the rectangular washery (comprising stand-tank and washing-floor) was covered with a colonnaded shed which provided shade and shelter from the weather, whereas the drying floor was open to sun and wind. Some washeries near Thorikos and at Soureza have preserved a single column-base embedded at the top end of the drying-floor – a raised foundation for a wooden upright supporting the front edge of the shed roof where it spanned the washery (Fig 18). The extra-wide Washery C at Agrileza revealed a row of three bases, which makes the form of the shed even clearer (Fig 19). Part of the shed's function was to shelter the workers where their activities were concentrated; another was to reduce evaporation from the stand-tank. Grooves for wooden shutters over the side channels at one or two washeries show that this was an important consideration. Even so, despite the recycling system, some water was sure to be lost by evaporation, and so the stand-tank would need to be topped-up at need from a nearby cistern.

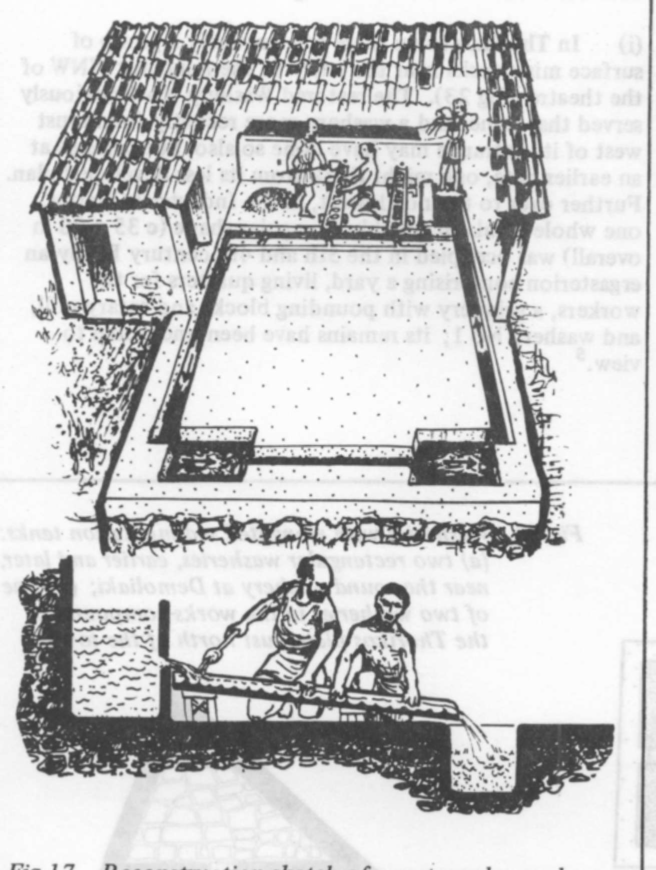


Fig 17 Reconstruction sketch of a rectangular washery (based on Agrileza A), showing the method of operation.

There are also other variants of rectangular washeries which diverge further from the type described above. In some there are, not round or square, but elongated sedimentation tanks, as in two examples at Demoliaki, high in the hills, while an excavated site in the Thorikos plain, north of the ancient town, has revealed washeries where the circulation system, formed of a series of tanks, surrounds the stand-tank rather than the drying floor (Fig 20).

(ii) Circular or Helicoidal Washeries

Only three examples of circular washeries have been recorded, all up in the Laurion hills: Demoliaki, north of Kamariza village, and Bertseco and Megala Pevka south of it. In form these were basically designed as an extended, circular form of the corrugated washing trough, formed of stone, with a stand-tank at one end (Fig 21). Water and ground ore was introduced at that end, and as there was a slight fall in the level of the channel (hence the term 'helicoidal' or 'spiral'), the water carried the material from cup to cup, depositing first rich ore, then poorer ore, then sand and silt, and reaching a lower tank in a clarified state; and from that it could be baled back into the adjacent stand-tank, so completing the circulation of the water. The trough was cut into the level upper surface of a series of large stone blocks, set end to end. At Demoliaki and at Bertseco the trough was ridged and hollowed, so that there was a continuous series of cups along its whole length (Fig 22). Megala Pevka was clearly an unfinished example, as the trough was not corrugated, had no cups, and at one end had been cut only to a shallow depth. Unfortunately, all three examples have been badly disturbed, so that only the blocks forming the trough remain **in situ**, while no traces remain of stand-tank and clarification tanks; the reconstruction sketch in Fig 21 must therefore be regarded as tentative.

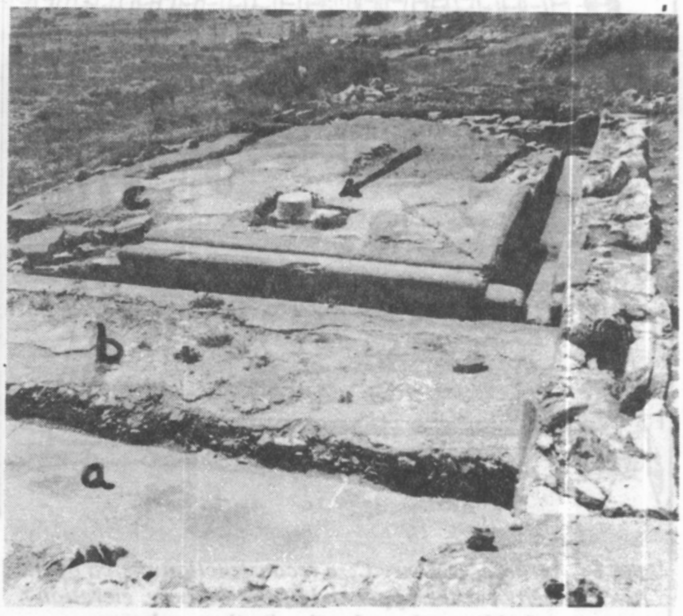


Fig 18 Thorikos plain: a washery behind the Belplast factory as cleared, with its main features lettered, and its single column-base arrowed. The base was for a timber pillar which supported the front edge of a shed-roof.

As only three examples of this ingenious form have been noted, it has been thought that it was a later development than the rectangular washeries, adopted just before the slump in mining in the late classical period. It was partly the discovery of these elaborate stone 'trough' washeries that allowed Professor Conophagos of the Athens Polytechnic to conjecture that simpler wooden troughs, also corrugated and with cups, had been used with the rectangular washeries as described earlier.[4]

V. Ergastiria : Workshops

Ore-washeries were probably only rarely isolated plants; more often they were part of some kind of working com-

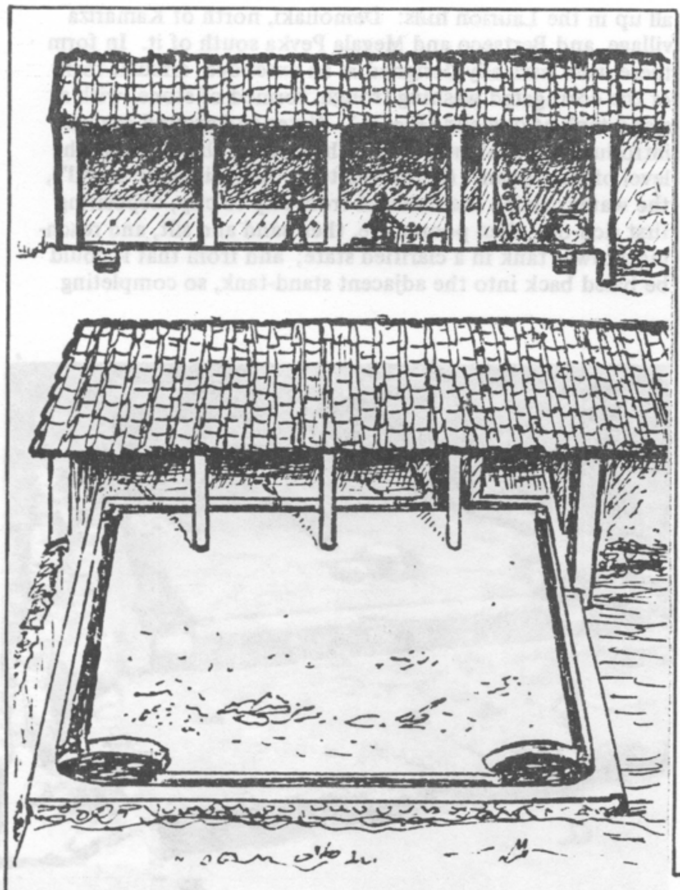
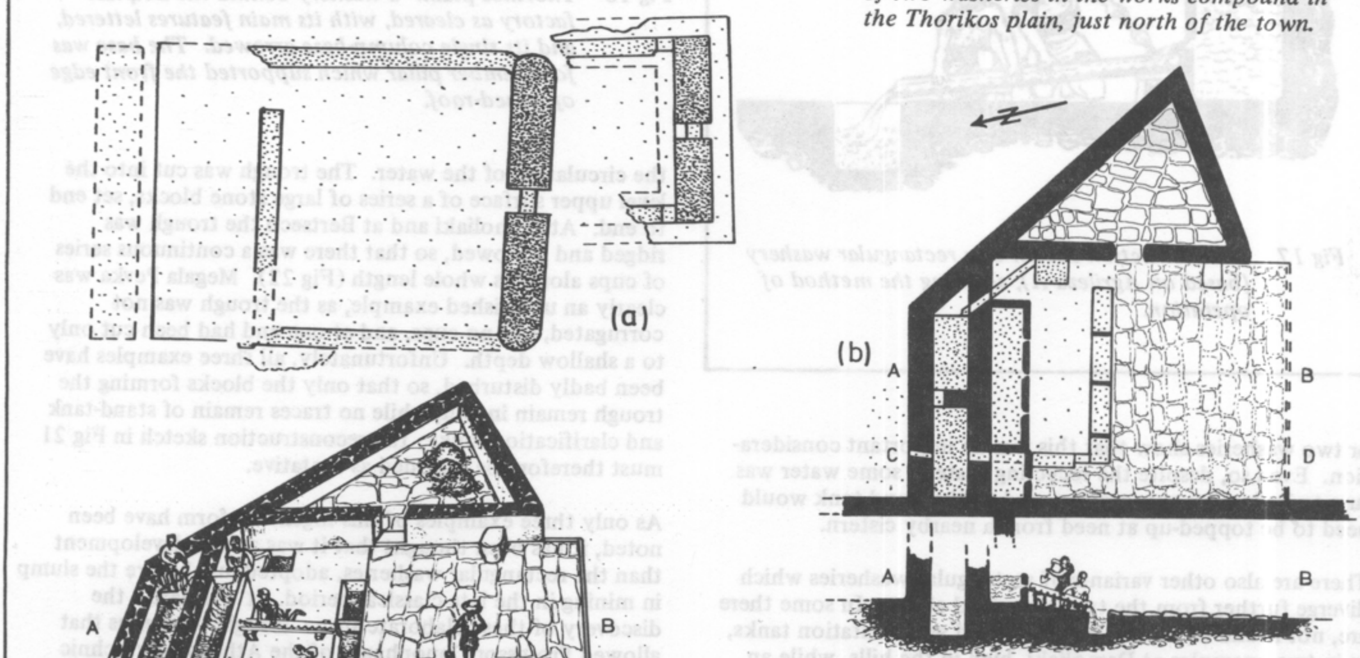


Fig 19 Agrileza, Washery C; a reconstruction sketch of the shed over the upper end of the washery, elevation and oblique view, showing its three columns.

pound, workshops, or factory ('ergasterion', pl 'ergasteria', in ancient Greek, from 'ergon' = work). Often, of course, the finely preserved cement floors and faces of the washery and its solid platforms have been easier to find than the other less substantial rooms and remains, so that this association with ancillary rooms has not been so much appreciated. But a number of works-compounds have now been explored: at Thorikos in the ancient town itself by the Belgian Archaeological Mission; at various points on the edge of the Thorikos plain by officers of the Greek Archaeological Service; at Soureza in the hill country by Professor C E Conophagos, former head of the Metallurgical Department of the Athens Polytechnic; and at Agrileza by the author on behalf of the British School at Athens. Brief comments on some of these are given.

(i) In **Thorikos town** there was probably a group of surface mineworks near the entry to the mine just WNW of the theatre (Fig 23). The restored Washery No 4 obviously served that mine, and a washery more recently found just west of its entrance may have done so also, but perhaps at an earlier date, one might think from its less developed plan. Further over to the north-west, in the Industrial Quarter, one whole insula of roughly triangular shape (c 35 x 20 m overall) was occupied in the 5th and 4th century BC by an ergasterion comprising a yard, living quarters for the workers, a grindery with pounding blocks and rotary mill, and washery No 1; its remains have been uncovered to view.[5]

Fig 20 Washeries with elongated sedimentation tanks: (a) two rectangular washeries, earlier and later, near the round washery at Demoliaki; (b) one of two washeries in the works-compound in the Thorikos plain, just north of the town.



(ii) In the **Thorikos Plain,** about 1 km north of the town, a rescue excavation revealed the greater part of a large compound (40 x 25 m overall), which has since been covered over again for its protection.[6] Planned on rectangular lines, it included two washeries of the type with a series of sedimentation tanks extending to the rear of the stand-tank, and a number of rooms, variously floored with cements, flags or earth (Fig.24). On the western edge of the plain, where washeries have been investigated on both flanks of a rocky knoll (Figs 16, 18), surface traces of walling on the western slopes indicate compounds and rectangular rooms.

(iii) At **Soureza,** two compounds have been fully cleared and left open to view, one being essentially rectangular in its layout and the other rather irregular but each with its inner yard surrounded by rooms, and its own washery and ancillary cisterns (Fig 25). Compound 2 had a grindery in front of its washery, with pounding blocks set in the corner of the rooms, and off the main yard had bathing facilities for the staff, an open washroom and a bathroom with hip-baths, perhaps for the slaves and the free staff respectively. Compound 3 possessed an 'andron' or dining-room, with plastered walls and floor and a raised surround to accommodate seven couches, where probably only the free-born managers might relax.[7]

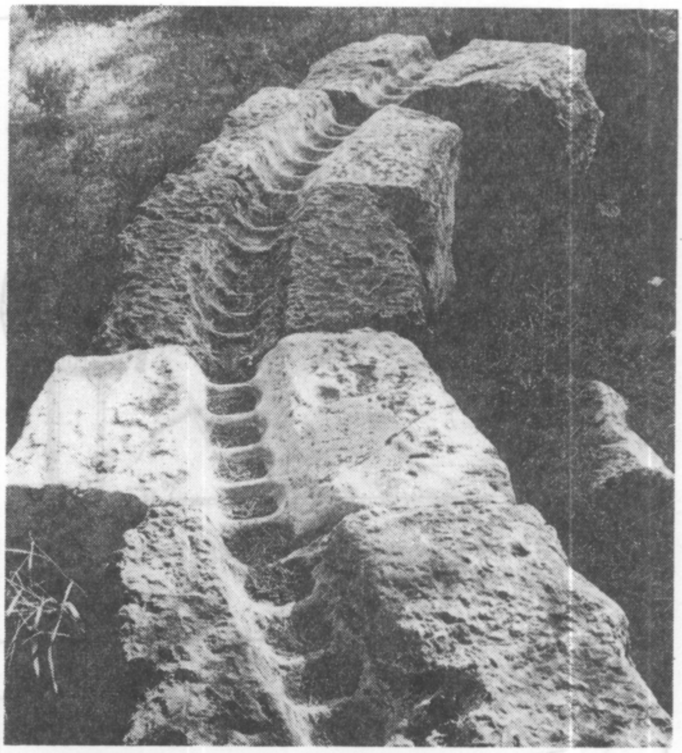
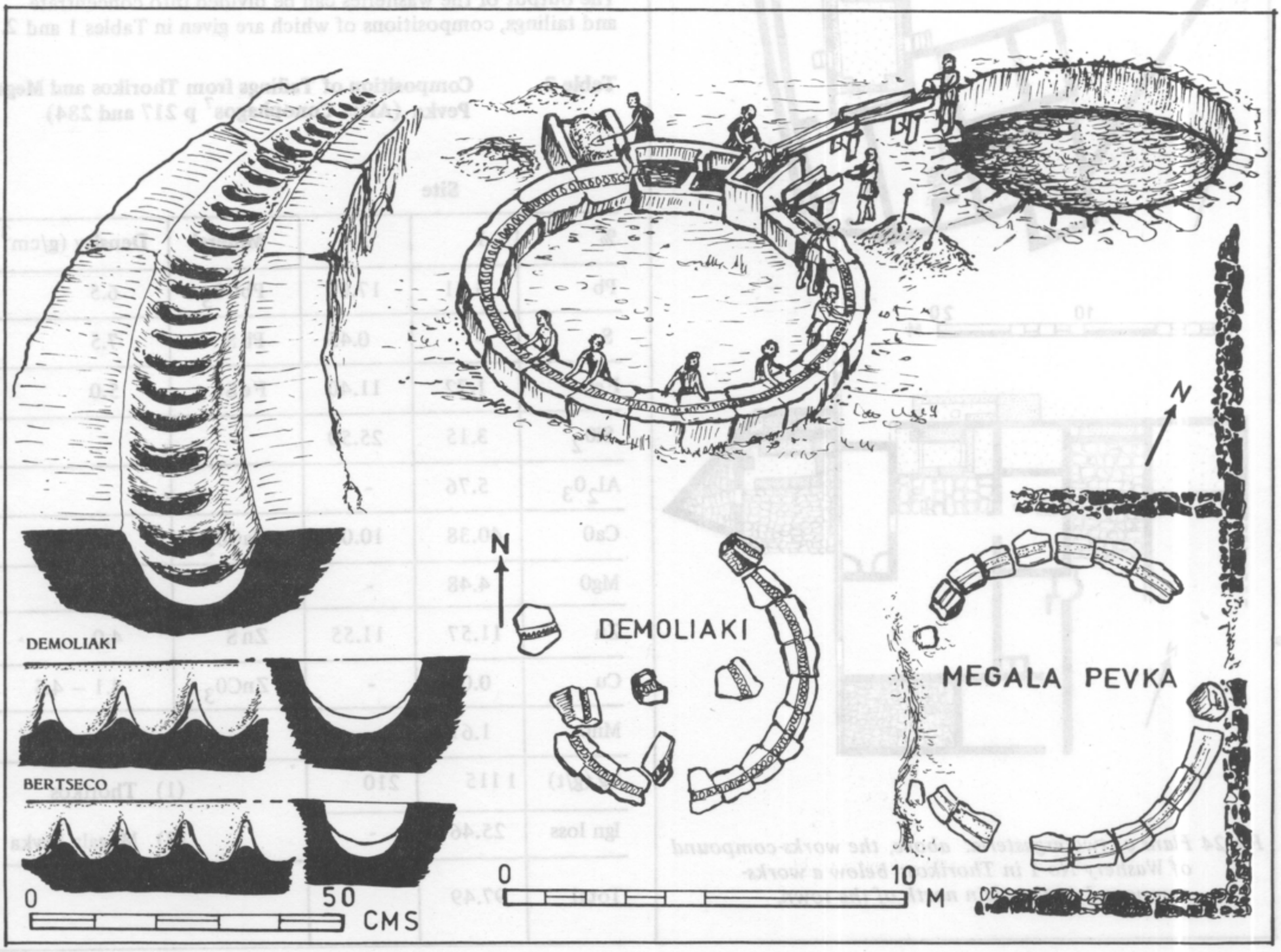


Fig 22 The helicoidal washery at Demoliaki; a close-up of the preserved remains showing the series of 'cups'.

Fig 21 Round or helicoidal washeries; plans of remains at Demoliaki and at Megala Pevka (unfinished) with a reconstruction sketch, and detailed sections of the troughs at Demoliaki and Bertseco.



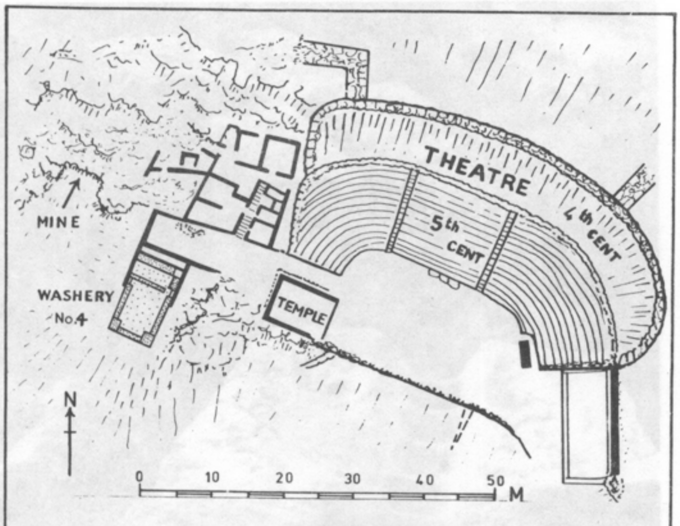


Fig 23 Thorikos town: the location of washery No 4 alongside the ancient theatre.

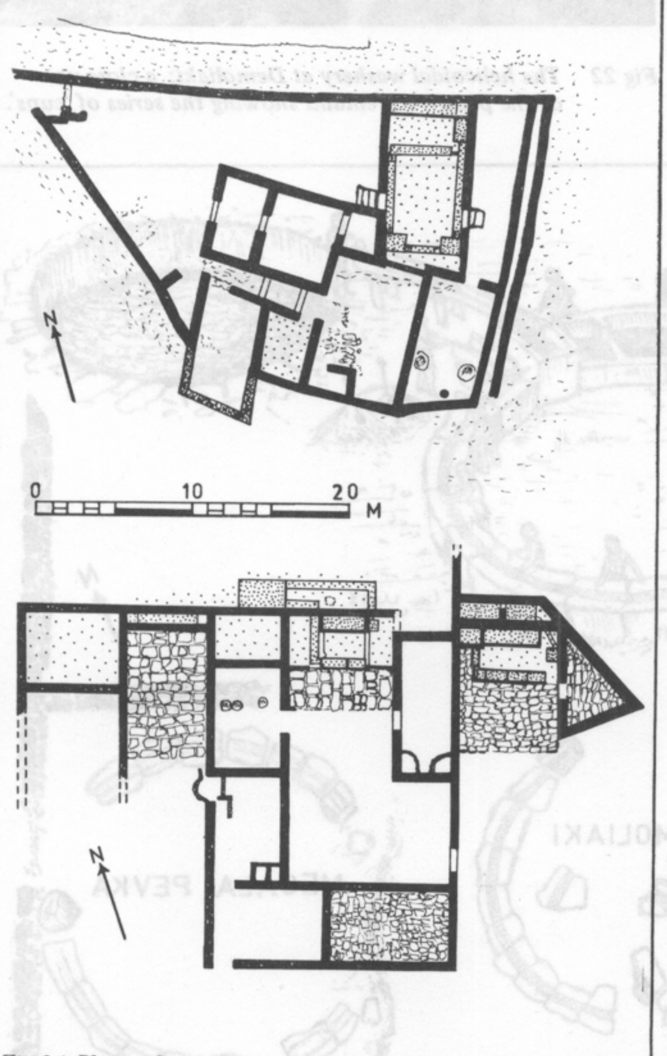


Fig 24 Plans of two ergasteria: above, the works-compound of Washery No 1 in Thorikos; below a works-compound in the plain north of the town.

(iv) At **Agrileza**, three ergasteria associated respectively with washeries A, B and C can be identified (Fig 26), either from surface traces (A,B) or from large-scale excavation (C).[8] The works-compound of Washery C is the largest (45 x 48 m), and was regularly planned and elaborately laid out in terraces on a hillside site (Fig 27). It had a south court terraced up on the south edge, with its washery at the west end and rooms along north and east sides; a ramped corridor led up from it to a north court, which had the washery's adjoining cistern at its west end and other rooms on the north and east. The pounding and milling of ore was undertaken here, as indicated by the many fragments of pounding blocks and hopper-querns. Some rooms were clearly workshops Metallurgical techniques well beyond ore-washing stages were carried out: hearths and work-benches were found, some associated with iron blooms, and also quantities of litharge, the lead-oxide-by-product formed when the metallic silver is separated out by re-heating and oxidization from the work-lead.

There must have been a considerable staff of workers, mainly slaves but with a few free-born managers and foremen to run these little 'factories'. A speech ascribed to Demosthenes (XXXVII, Against Pantaenetus, 4) discusses a dispute about ownership of such a property, and an ergasterion with thirty slave workers is mentioned; whether that was normal, or below or above average, is not known. At many if not all such ergasteria, some rooms were probably used to lodge the slaves; the daytime 'mess-room' of the free managerial staff at one of the Soureza compounds has already been noted.

The output of the washeries can be divided into concentrate and tailings, compositions of which are given in Tables 1 and 2.

Table 2 **Composition of Tailings from Thorikos and Megala Pevka (After Conophagos[7] p 217 and 284)**

	Site			
%	**1**	**2**	**Mineral**	**Density** (g/cm^3)
Pb	3.31	17.00	$PbCO_3$	6.5
S	-	0.45	PbS	7.5
FeO	1.72	11.40	FeS_2	5.0
SiO_2	3.15	25.50		
Al_2O_3	5.76	-		
CaO	40.38	10.0	$CaCO_3$	2.6 – 2.8
MgO	4.48	-		
Zn	11.57	11.55	ZnS	4.0
Cu	0.047	-	$ZnCO_3$	4.1 – 4.5
MnO	1.61	-		
Ag (g/t)	1 115	210		
Ign loss	25.46	-		
Total	97.49			

(1) Thorikos

(2) Megala Pevka

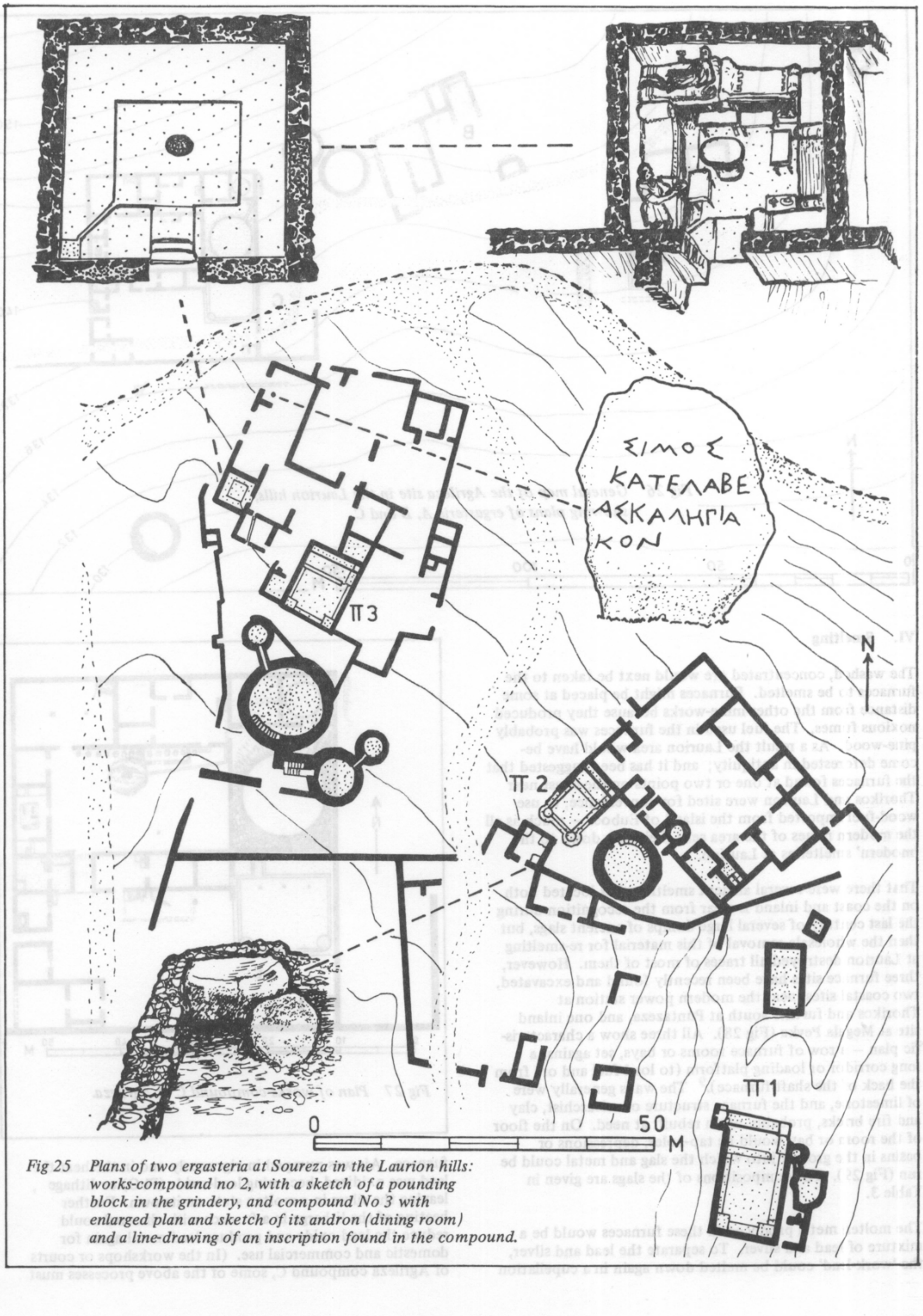


Fig 25 Plans of two ergasteria at Soureza in the Laurion hills: works-compound no 2, with a sketch of a pounding block in the grindery, and compound No 3 with enlarged plan and sketch of its andron (dining room) and a line-drawing of an inscription found in the compound.

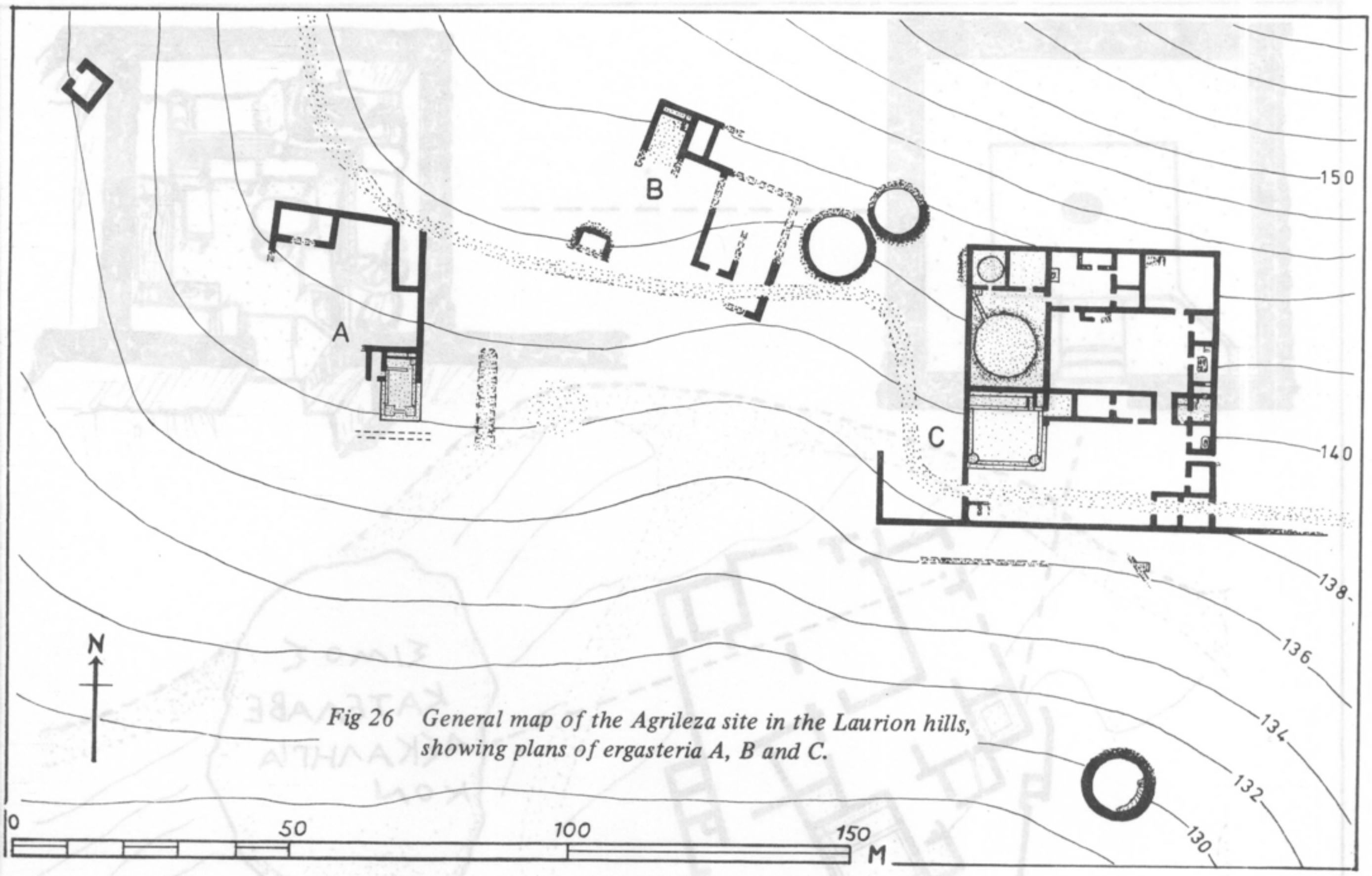


Fig 26 General map of the Agrileza site in the Laurion hills, showing plans of ergasteria A, B and C.

VI. Smelting

The washed, concentrated ore would next be taken to the furnaces to be smelted. Furnaces might be placed at some distance from the other mine-works because they produced noxious fumes. The fuel used in the furnaces was probably pine-wood. As a result the Laurion area would have become deforested in antiquity; and it has been suggested that the furnaces found at one or two points on the coast near Thorikos and Laurion were sited for convenience, to use wood-fuel imported from the island of Euboea – much as all the modern mines of the area sent their ores down to the 'modern' smelteries at Laurion.

That there were several ancient smelting sites located both on the coast and inland is clear from the recognition during the last century of several large dumps of ancient slags, but then the wholesale removal of this material for re-smelting at Laurion destroyed all traces of most of them. However, three furnace sites have been recently found and excavated, two coastal sites, near the modern power station at Thorikos and further south at Puntazeza, and one inland site at Megala Pevka (Fig 28). All three show a characteristic plan – a row of furnace rooms or bays, set against a long corridor or loading platform (to load fuel and ore from the back of the shaft furnace).[9] The walls generally were of limestone, and the furnace structure of micaschist, clay and fire bricks, probably often rebuilt at need. On the floor of the room or bay would be tap-holes, depressions or basins in the ground into which the slag and metal could be run (Fig 29). The compositions of the slags are given in Table 3.

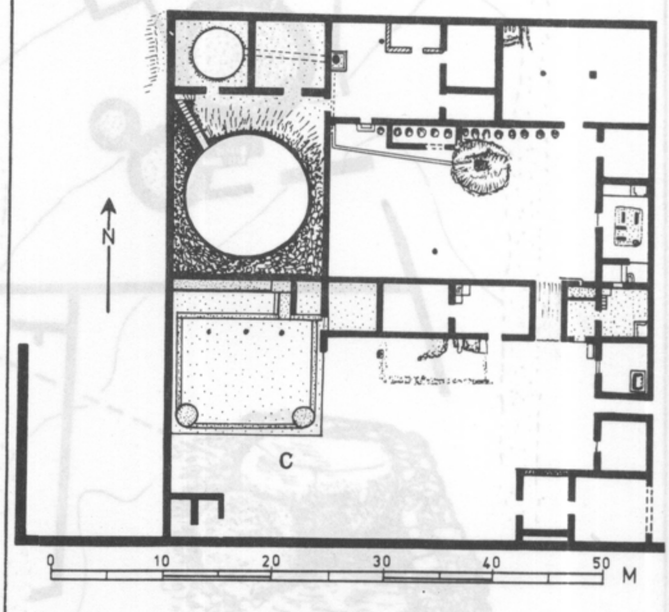


Fig 27 Plan of works-compound C at Agrileza.

The molten metal produced in these furnaces would be a mixture of lead and silver. To separate the lead and silver, the 'work-lead' could be melted down again in a cupellation furnace. Air was pumped in vigorously and in the heat the lead was oxidized, becoming lead-oxide (PbO) or lithage , leaving the silver in a molten state on its own. Further heating of the litharge in a furnace with charcoal could reduce the lead-oxide and produce lead metal again for domestic and commercial use. (In the workshops or courts of Agrileza compound C, some of the above processes must have been carried out, as litharge has been found in quantities; but perhaps the process of smelting was done on a smaller scale on smaller hearths, as no row of furnace-rooms or bays has been located there.)

Table 3

Analyses of Slags from Early Smelting Sites in the Laurion Area (%)

	Megala Pevka		**Panormos**
	MP1	**MP2**	**PAN 5**
SiO_2	33.50	29.62	30.92
Al_2O_3	6.84	5.73	5.13
CaO	25.30	19.23	16.65
MgO	1.98	1.75	3.12
FeO	11.67	11.28	11.33
PbO	8.70	19.26	15.17
ZnO	8.88	6.48	15.03
Sb_2O_3	0.38	0.34	0.51
S	0.09	0.10	0.15
P_2O_5	0.36	0.37	0.43
TiO_2	0.37	0.28	0.19
K_2O	1.74	1.61	1.68
MnO	0.27	0.28	0.71
	100.08	96.33	101.02

These slags all contain undigested crystals of fluorspar (CaF_2) which melts at about 1320°C and traces only of Cu, As, Cr and Ni.

Analysed by microprobe in the Geology Dept. Oxford by NH Gale and Z A Stos-Gale,

The silver product of the mines was taken to Athens to be minted into coinage by the state and to supply the manufacturers of jewellery and plate; their export trade to the cornlands of the Aegean, the Black Sea and elsewhere was one of the props of Athenian commercial solvency. The mint of Athens was situated at the south-east corner of the Ancient Agora or market-place (near and under the restored Church of the Twelve Apostles, although excavations so far have only found traces of bronze working). Somewhere here probably would be struck the famous 'owls of Athens' the silver coins or drachmas with the head of Athena on one side and her symbol the owl on the other.

The other products of the Laurion mines must not be forgotten. The lead was used for commercial and domestic purposes, though doubtless on a lesser scale in the classical period than in Roman times; it was used in industry and buildings, for sealing purposes of many kinds (even to the extent of being made into rivets for repairing broken pots). Iron was another product, used locally for miners' tools and for a host of other purposes elsewhere. Laurion is thought to have contributed directly to the erection of some of the glorious monuments of the Athenian Acropolis -its iron providing clamps to hold their marble blocks together and its lead being used to seal and fix those clamps in place. Copper likewise was a valued product of the district from long before the classical period; recent analyses have detected the characteristic Laurion lead isotope ratios in lead traces in bronze and copper artefacts from several places in the Aegean area, dating back at least to the late Bronze Age and earlier.[10]

VII. History of the Industry

Some mining was done in the Thorikos – Laurion area as early as the Middle Bronze age, for litharge fragments have been found at Thorikos in an archaeological context of c 1500 BC[11]. Litharge from a house of c 900 BC shows that mining was carried on in the Geometric period also[12]. Probably exploitation was on fairly small scale in these early centuries BC.

It has been thought that the Athenian despot Peisistratus gave an impetus to the mining industry. He was indeed from Brauron, only a few miles up-coast from Thorikos. His first attempt to seize control of Athens in 560 BC ended in 565; he fled to the Chalcidice and Thrace, where he developed an interest in the silver mines of that area, and won enough wealth to build a private mercenary army. He returned to Athens in 546 BC to become tyrant, and probably did much to develop the silver mines of Laurion, which would help to pay for his many building projects.

Early in the 5th century, in 484/3 BC a new source of silver was found, when perhaps the deep, third contact was located. The sudden production gave a surplus of wealth; Themistocles was able to divert 100 talents into building a war fleet which helped to win the battle of Salamis and eventually create an Athenian Empire.

Therefore certainly by the 480s state control can be assumed. Only a little extant epigraphical and literary evidence relates to the mines in the 5th century BC; an inscription of c 423 BC and references in Aristophanes' **Wasps** and Pherecrates' comedy **Miners** indicate state control and interest.

Production was on a large scale till the Peloponnesian war (431-404 BC) began to disrupt it, especially after the Spartans created a permanent base at Dekeleia, just north of Athens, in 412 BC. The historian Thucydides tells us that then up to 20,000 slave-workers deserted the mines and workshops to join the Spartans. Production ceased with the defeat of Athens.

Knowledge of a revival in the 4th cent BC is largely based on inscriptions preserving lease-lists of the mines and some literary allusions.[13] Xenophon's pamphlet **Ways and Means** advocated a renewal of mining to strengthen the Athenian economy. The financial policy of the political leader Callistratus (373-366BC) led to a resumption of operations. A boom started with the War of Athens and her allies

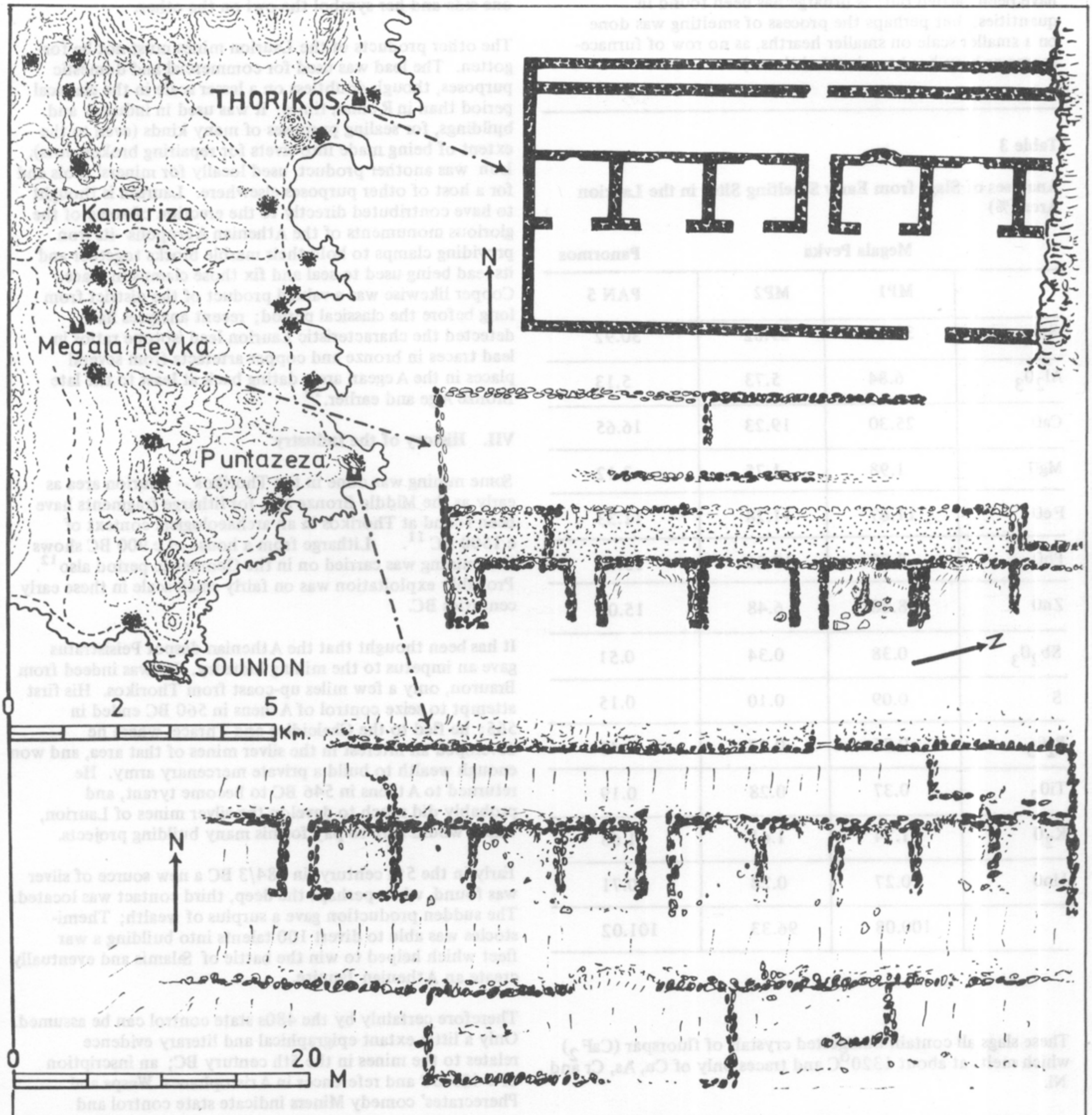


Fig 28 Location map and plans of the three smelting sites at Thorikos, Megala Pevka, and Puntazeza. The black pots on the map mark the location of ancient slag heaps, mapped in the 19th century ; they indicate other smelting sites, traces of which were destroyed when the slag was transported for re-smelting.

(357-355 BC) and continued under the management of the finance-politicians Eubulus (354-340 BC) and Lygurgus (338-326 BC).

In the 4th century BC the state officials called **poletai** auctioned contracts or leases for the mines of Laurion, leasing individuals mines for set periods of years to private speculators. This implies that the mining rights and the underground mine **(metallon)** belonged to the state. Productive mines were leased for three years, new mines which required much unproductive digging first, and unprofitable old mines, were leased for longer. The **poletai** drew up a list of lease-holders and some such lists are extant (if incomplete on inscriptions) for the period 367-306 BC. Mine areas are defined by reference to boundaries of different properties, roads, streams etc. Leaseholders paid rent to the state, and often marked their 'claim' on the mine-area with an inscription, such as that found in one of the Soureza compounds: **Simos katelabe Askalepiakon,** ie 'Simos has leased the Asklepiakon mine'. The surface-works (washeries, ergasteria etc) were on private land and privately owned, and built by the owners often for private speculation, either to work themselves to serve nearby mines for a fee, or to rent to the mining-concessionaire for a period of years. Sometimes these ergasteria would be used as sureties in finance deals, or would be mortgaged to raise loans on their value. Such a deal is mentioned in the speech of Demosthenes already cited, while the author has found at Agrileza evidence for two separate mortgage deals on Washery C, attested by two fragmentary inscriptions. Both are **Horos** (= boundary) stones noting that the property is mortgaged, so giving due warning to any third party. The property could be 'released' on repayment of the mortgage loan.

Towards the end of the 4th century BC there was a decline in the industry, perhaps a slump, partly as a result of Athens' political weakness, partly as a result of a shift from the silver standard of Athenian coinage to the gold standard of the Macedonian kings, who minted gold staters in great quantities. The last lease-list dates to 307-306 BC.

In the Hellenistic period there was still some limited production. A slave rising in 135 BC involved however only a few thousand slaves. In the second half of the 1st century BC minting of Athenian silver tetra-drachmas ceased (so there was less reason to mine silver), and the writer Strabo records, in the late 1st century BC or early 1st century AD, that the mines were worked out and that Thorikos and other places, once prosperous towns, were then just names (ie had become ghost-towns, like so many modern mine-rush towns).

In Roman times there was indeed some production of silver, but possibly more because there were efforts made then to resmelt the ancient slag-heaps to extract the metals wasted earlier on, rather than as a result of active mining. Thereafter, for centuries, mining in the area was unknown until it was revived in the mid-19th century AD. By now, most of the buildings and surface- works of that modern boom are also mouldering away, often side by side with the monuments of antiquity and competing with them for the interest of the industrial archaeologist and the Historical Metallurgist.

Fig 29 Conjectural reconstruction sketches of a furnace site (after Conophagos).

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Machining wrought iron with carbon steel tools

E M Trent and E F Smart

Wrought iron and cast iron were the most important metallic materials in engineering structures from the early days of the industrial revolution until about 1860 to 1880. To produce the required shapes to specified accuracy, starting with rough forgings, hot-rolled products and castings, a very large amount of metal had to be removed by machining. The technology of machining cast iron is now highly developed because it is still a major engineering material. It is many years since wrought iron was made or machined and it is of interest to look at the problems encountered.

Throughout the 19th century almost all machining of wrought iron was with carbon steel tools because there was no alternative. After 1868 Mushet's 'self-hardening' tool steels were available but were usually reserved for difficult operations. High speed steel tools were marketed after 1900. Table I, reproduced from an article by J W E Littledale[1] in 1901, gives some idea of the speeds and feeds for engineering materials before the general introduction of high speed steels. For wrought iron the speeds varied from 38 to 18 ft/min. Speeds about 20-40% lower were suggested for steel, than for wrought iron. F W Taylor[2] gives a typical speed for carbon steel tools cutting a 0.34%C steel as 16 ft/min and using Mushet steel as 26 ft/min.

Table of Cutting Speeds – *For Steel*

Diameter of Work	Roughing Cut		Finishing Cut	
	Speed in Feet per Minute	Revolutions to Feed Tool 1 inch	Speed in Feet per Minute	Revolutions to Feed Tool 1 inch
1 in and less	20	25	20	30
1 in to 2 in	18	25	18	30
2 in to 3 in	18	15	15	30
3 in to 6 in	15	12	15	30
	For Wrought Iron			
1 in and less	35	25	38	30
1 in to 2 in	25	20	30	30
2 in to 4 in	25	20	25	25
6 in to 12 in	20	15	23	20
12 in to 20 in	18	13	18	16
	For Cast Iron			
1 in and less	38	20	38	20
1 in to 2 in	35	20	35	16
2 in to 4 in	30	20	30	10
4 in to 6 in	25	15	25	6
6 in to 12 in	20	14	20	6
12 in to 20 in	20	10	20	4
	For Brass			
1 in and less	120	25	120	25
1 in to 2 in	100	25	100	25
2 in to 4 in	80	25	100	25
4 in to 6 in	70	25	70	25
6 in to 12 in	60	25	70	25
	For Copper			
1 in and less	350	25	400	25
2 in to 5 in	250	25	300	25
5 in to 12 in	200	25	200	25
12 in to 20 in	150	25	150	25

Table 1 J W E Littledale 1901[1]

Table I shows cutting speeds for several values of feed. Notably high feeds – eg 0.033 to 0.076 inch per revolution – were used compared with modern practice. At such high feeds a normal feature of tool geometry was a very large nose radius or a round-nosed tool. The use of these tool shapes greatly reduced the thickness of the chip, an effect equivalent to reducing the feed, the undeformed chip thickness being much smaller than the feed.

Experimental Work

For the experimental investigation a carbon steel tool was obtained, dated from the 19th century and stamped with the mark of Messrs Boulton and Watt. The composition is given in Table 2. The tool was sectioned through the cutting edge and this region had a martensitic structure, tapering off to sorbite less than half an inch from the edge. The hardness varied from 810 to 850 HV. The tool had probably been hardened by heating the cutting end in a coke fire to 'cherry-red heat' and quenching in water. The steel was very clean as regards non-metallic inclusions and was certainly the product of crucible steel making. The other end of the tool had not been hardened and tool tips for experimental machining were cut from this end. The tool tips were hardened by water quenching from a salt bath at 780°C and tempered at 230°C. The hardness was approximately 750 HV.

Bars of wrought iron for machining tests were not easy to obtain but suitable material was supplied to us from original material being rejected in the reconstruction of the SS Great Britain. Two pieces from a tie-bar 3¼ inch diameter by 2 ft long were supplied. This material had a typical wrought iron structure consisting of ferrite grains and elongated slag particles of a range of sizes as shown in Figure 1. A few areas with cementite particle at grain boundaries were observed, but no major high carbon areas with pearlite. The slag particles appeared to consist of wustite (FeO) and fayalite ($2FeO.SiO_2$). Across the section there was considerable heterogeneity in distribution of slag particles of various sizes, as was normal for wrought iron.

For the machining tests a continuous turning operation was used. The tool tips were clamped into a tool holder and used to cut the wrought iron for a period of 5 minutes. In view of the relatively small amount of material available for test, this time was selected as being long enough to demonstrate the main factors in tool life. After some preliminary work, the main tests were carried out at a feed of 0.020 inch per rev and a depth of cut of 0.125 inch, using tools with a zero approach angle and a nose radius of 0.035 inch. These conditions were selected as feasible experimental conditions, with an un-deformed chip thickness such as might have been involved in some 19th century machining operations, as discussed above.

Composition of Boulton and Watt Steel Cutting Tool

Carbon	1.24%
Silicon	0.113
Manganese	0.12
Sulphur	0.018
Phosphorus	0.019

Ni, Cr, Mo, W, V, Cu and Sn all less than 0.01%

Table 2

Most of the tests were terminated by use of a 'Quick-stop' device. This is a mechanism for propelling the tool downward very rapidly, using an explosive charge, to preserve a 'frozen' picture of conditions at the tool edge during cutting. The results discussed here were obtained by metallographic studies of worn areas of the tools and of sections through the corresponding chips as they were being formed.

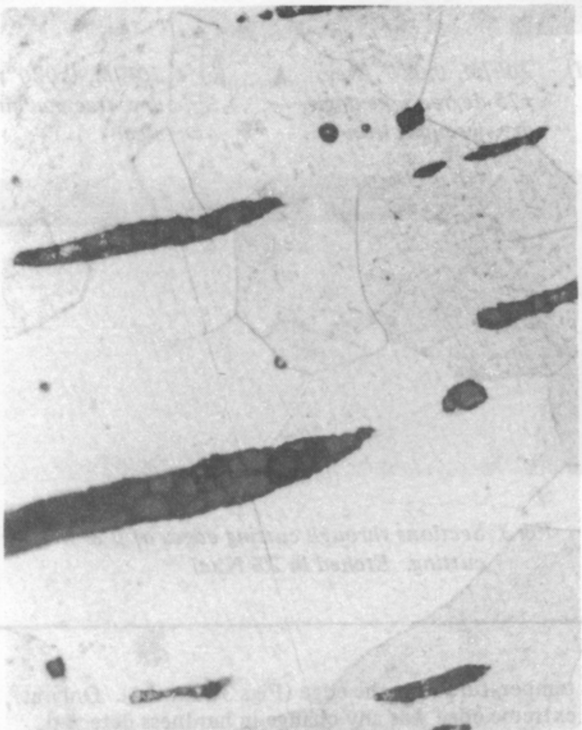


Fig 1 Structure of wrought iron. SS Great Britain X400

Estimates of the temperature distribution in the tools near the cutting edge during the cutting operation were made by measuring the change in hardness of the tools near the edge after cutting. Micro-hardness measurements were made on polished sections through the tool edge using a Vickers diamond indenter with a load of 300 gms. Hardness indentations were spaced 0.1 mm apart (Figure 2). Hardness measurements were converted to temperature by calibrating this tool steel. The hardness of small specimens of the hardened tool steel was measured after re-heating for 5 minutes in a salt bath at temperatures from 250 to 550°C.

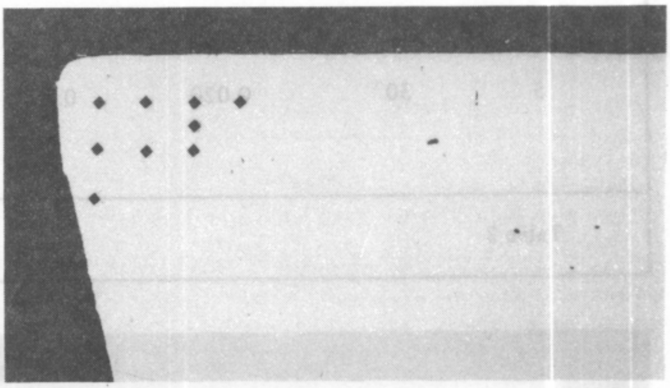


Fig 2 Sectioned cutting tool showing the distribution of micro-hardness impressions X60

Machining Tests

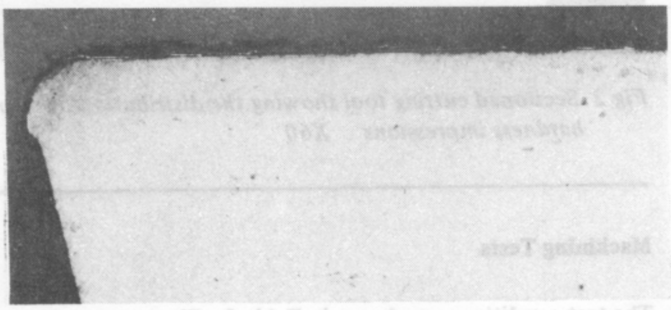
The test conditions are shown in Table 3. The tests were terminated after 5 minutes by a quick-stop. The tools came away from the work material nearly cleanly, leaving thin smears and layers of work material on the tool surface. Sections were prepared through the worn tool edges and photo-micrographs of these, etched in Nital are shown in Figure 3. In all cases the cutting edges, initially sharp, were plastically deformed during cutting. The region near the cutting edge is more darkly etched than the body of the tool, the martensite having been tempered in this region by the heat of the cutting operation. Figure 4 shows the temperature contours estimated from micro-hardness measurements in the heat-affected regions, which are the regions darkened by the Nital etch.

In all cases plastic deformation, rather than wear, played the major part in changing the shape of the tool edge and the plastic deformation is clearly associated with the rise in temperature near the edge. The maximum observed temperature was 350°C for tool No 1, at a cutting speed of 10 ft/min, and 450°C for tool No 2, at 15 ft/min, cutting without a coolant. The highest temperature was at the deformed cutting edge, and clearly the effective heat source was concentrated at this position. Figure 5 shows the extreme localized deformation to a depth of 0.1 mm or more at the worn surface of tool No 2 (Position A in Figure 3B). Note that a thin layer of iron remains bonded to the whole of the visible worn surface. Tool No 2 was probably near the point of complete collapse but chip formation continued normally for the whole 5 minutes cutting.

Tool No 3 was used under the same conditions as tool No 2 except that a water-based cutting fluid was flooded over the cutting edge. The coolant was very effective in reducing

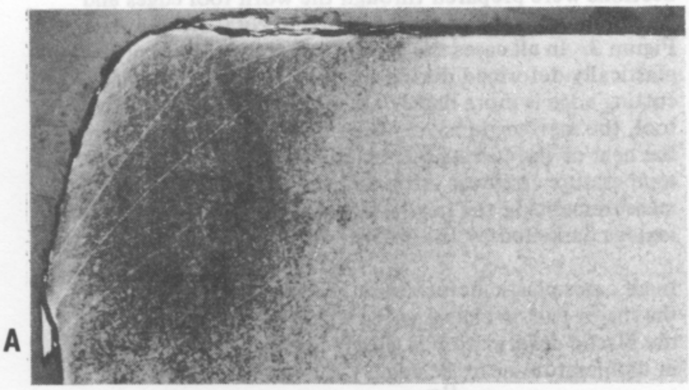
Test No	Cutting speed ft/min	Feed inches per rev	Depth of cut inches	Cutting time minutes	Rake angle	
1	10	0.020	0.125	5	6°	Dry
2	15	0.020	0.125	5	6°	Dry
3	15	0.020	0.125	5	6°	Coolant (Shell Metallina)
4	20	0.020	0.125	5	25°	Dry
5	30	0.020	0.125	5	6°	Material machined – 0.1%C, high S free-cutting steel

Table 3

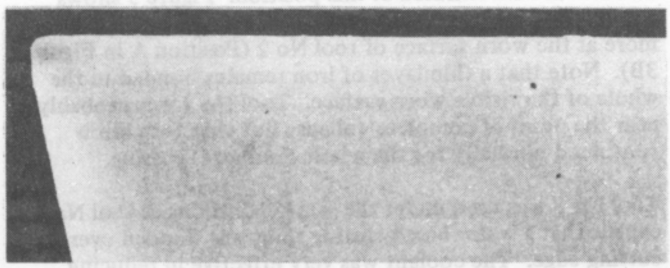


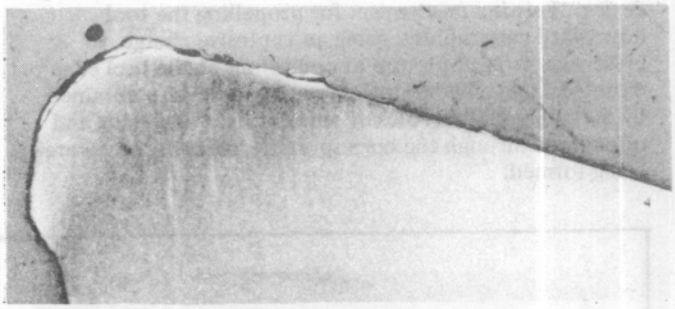
(a) 10F/M 0.020"/Rev, dry, wrought iron

(b) 15F/M, 0.020"/Rev, dry, wrought iron



(c) 15F/M, 0.020"/Rev, water based coolant, wrought iron





(d) 20F/M, 0.020"/Rev, +25 degree rake angle, dry, wrought iron

(e) 30F/M, 0.020"/Rev, dry, free machining steel

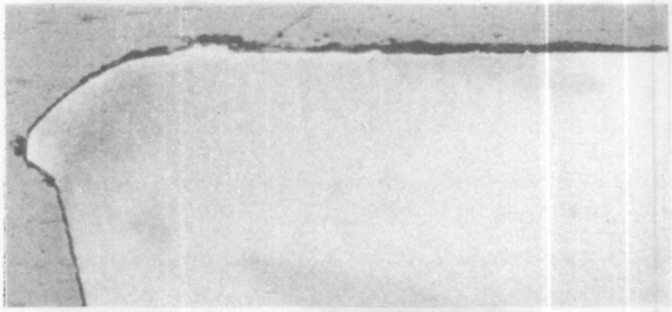


Fig 3 Sections through cutting edges of B & W after cutting. Etched in 2% Nital

the temperature near the edge (Figs 3c and 3d). Only at the extreme edge was any change in hardness detected, indicating a temperature below 300°C. There was only a small change of shape of the tool edge by plastic deformation.

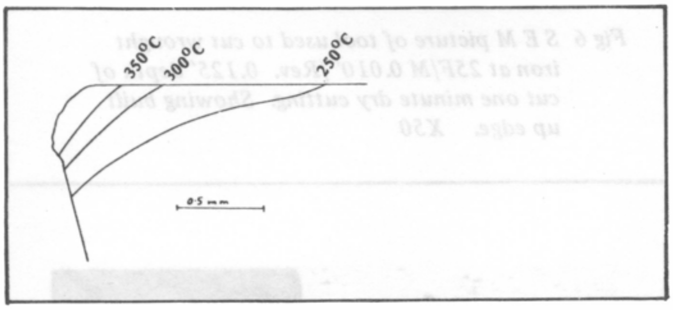
Tools used in the first three tests had a rake angle of +6°. This is a small rake angle for steel tools, and tool No 4 had a rake angle of +25°. It was used to cut the wrought iron at 20 ft/min because it was expected that the higher rake angle would permit a higher cutting speed. Figures 3d and 4d show that the maximum temperature at the tool edge was 400°C, and that the shape of the edge had been considerably changed by plastic deformation. Normal chips were still being formed when cutting was terminated. As with the other tools, a thin layer from the wrought iron was bonded to most of the worn surface.

For comparison, the final tool in this test series was used to cut a low carbon steel (0.1%C) with high sulphur content – a free-machining steel of modern origin. Figures 3e and 4e show the plastic deformation and temperature distribution in the tool used at 30 ft/min. The maximum temperature, over the deformed rake face at the tool edge, was 400°C. The heat affected zone extended further back along the rake face than when cutting wrought iron and the shape of the deformed edge was different. It is interesting that a considerable increase in cutting speed, was possible with the free-machining steel compared with wrought iron.

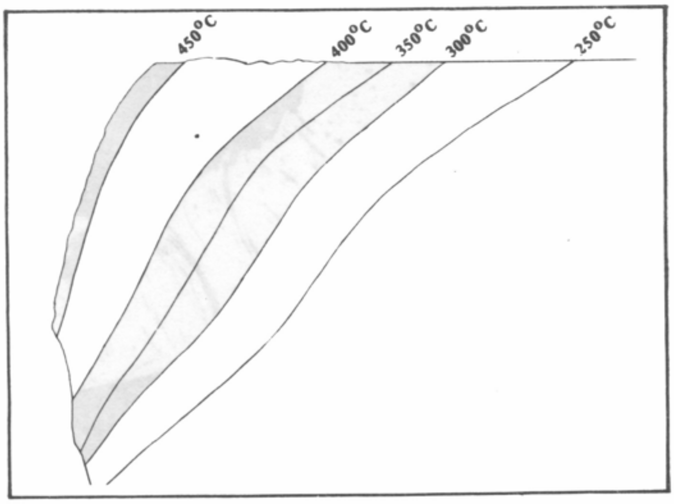
Chip Formation

A common feature of the low speed machining tests with wrought iron was the formation of a built-up edge. When cutting was stopped by disengaging the feed, the build-up edge often remained adherent to the tool, as shown in the SEM micrograph Figure 6, after cutting for 1 minute at 25 ft/min at a feed of 0.10 inch per rev. After a quick-stop, most of the built-up edge usually remained on the forming chip, leaving a very thin layer of iron attached to the tool (Figure 5). Figure 7 shows the formation of the built-up edge. A built-up edge is a normal feature when cutting alloys with more than one phase at low speed, and with wrought iron the slag particles appear to act as an effective second phase. Hardness in the undeformed wrought iron was 92-126 HV. Within the body of the chip this increased to about 170 HV, and in the extremely work-hardened built-up edge, to 220 – 285 HV. Figure 8 shows a detail with the built-up edge structure on the right and the almost undeformed wrought iron on the left. In the built-up edge, the slag inclusions are drawn out by plastic deformation of the fayalite (dark), the wustite constituent (light) maintaining its size and shape.

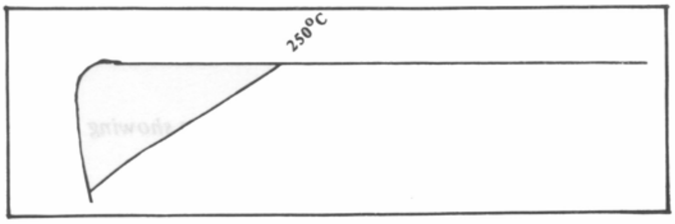
In this mode of chip formation, the tool is heated mainly from the energy expended in deformation at the top of the built up edge. The heat is conducted through the built-up

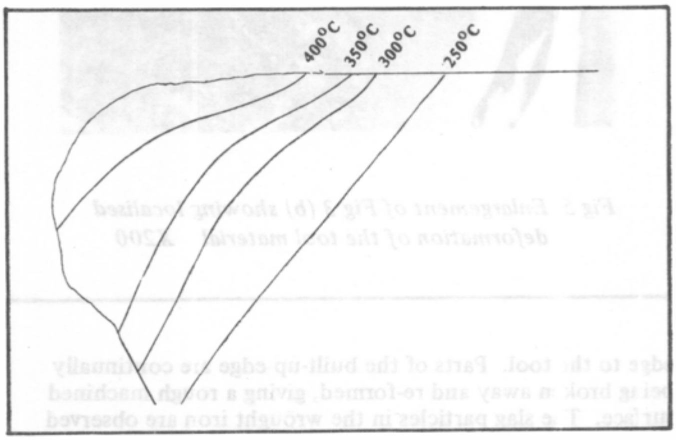


(a) From Fig 3 (a) ▲ ▼ *(b) From Fig 3 (b)*

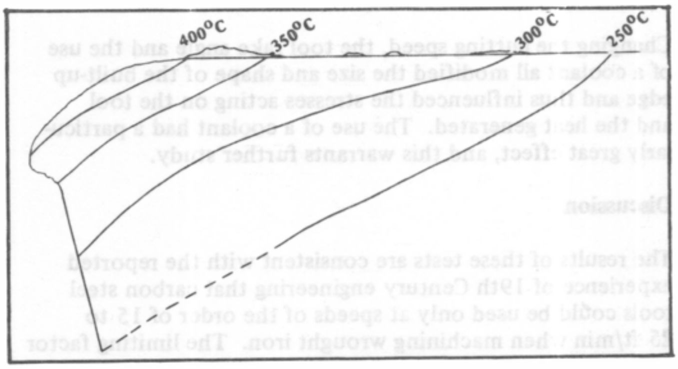


(c) From Fig 3 (c) ▲





▲ *(d) From Fig 3 (d)*



▲ *(e) From Fig 3 (e)*

Fig 4 Temperature isotherm diagrams for sections of B & W tools shown in Fig 3

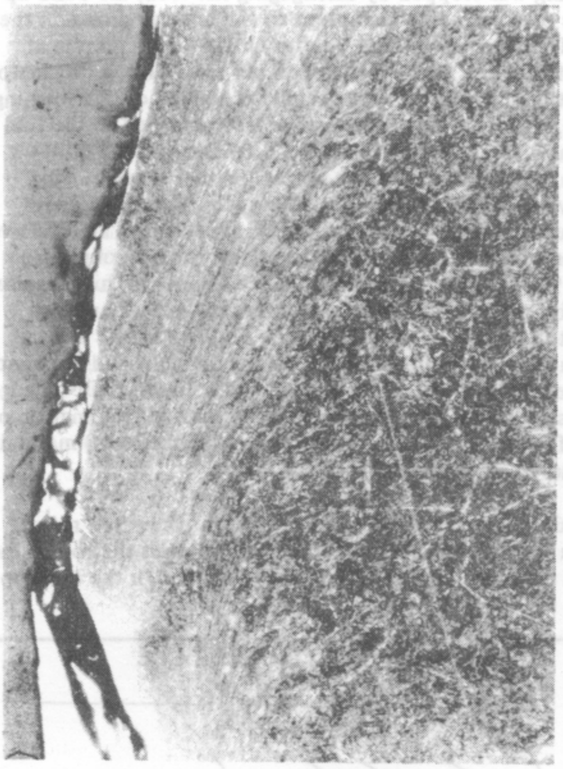


Fig 5 Enlargement of Fig 3 (b) showing localised deformation of the tool material X200

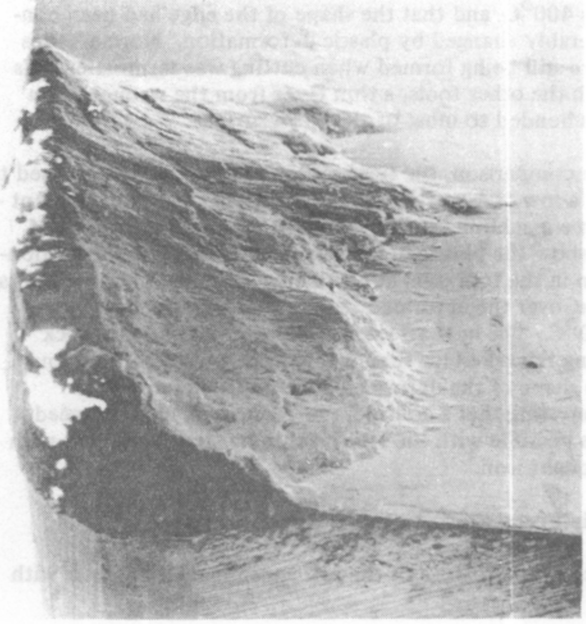


Fig 6 S E M picture of tool used to cut wrought iron at 25F/M 0.010"/Rev. 0.125" depth of cut one minute dry cutting. Showing built up edge. X50

Fig 7 Quick stop section of forming chip showing built up edge. X30

edge to the tool. Parts of the built-up edge are continually being broken away and re-formed, giving a rough machined surface. The slag particles in the wrought iron are observed to play a major role in initiating and propagating the fractures which form the new work surface and the under side of the chip. The origin of the new work surface can be seen at the end of the vertical fracture in Figure 8.

Changing the cutting speed, the tool rake angle and the use of a coolant all modified the size and shape of the built-up edge and thus influenced the stresses acting on the tool and the heat generated. The use of a coolant had a particularly great effect, and this warrants further study.

Discussion

The results of these tests are consistent with the reported experience of 19th Century engineering that carbon steel tools could be used only at speeds of the order of 15 to 25 ft/min when machining wrought iron. The limiting factor was the ability of carbon steel tools to withstand the stresses imposed at the tool edge at temperatures of the order of 300 to 450°C which increased as the cutting speed was raised. The shape of the tool edge seems to have been changed mainly by plastic deformation. Even at speeds as low as 10 ft/min, deformation occurred early in the tool life, but the tool continued to cut for relatively long periods before complete failure, the chips coming away with rather little change in character. This can be explained by the presence of a built-up edge of a stable form. The chip was being formed over the built-up edge rather than directly over the rounded tool edge.

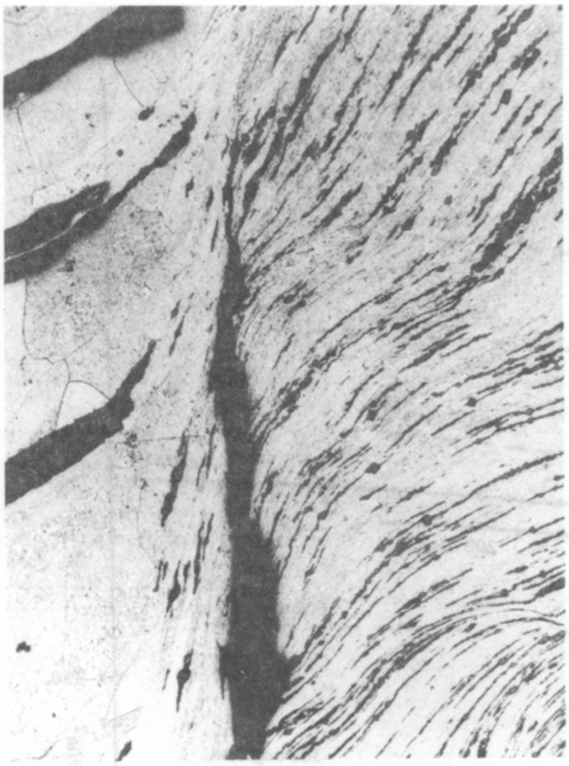


Fig 8 Detail of Fig 7 showing B U E structure on the right of picture and undeformed wrought iron on left. X160

There are few significant recorded observations from the 19th century of the mode of failure of carbon steel tools. The following description from F W Taylor's 'On the art of cutting metals'[2] suggests that failure by plastic deformation of the tool edge was the normal mode:

Page 82/83 'With carbon steel tempered tools at standard speeds the cutting edge begins to be injured almost as soon as the tool starts to work, and is entirely rounded over and worn away before the tool finally gives out, and the tool works well in spite of its edge being damaged. . . . Carbon steel tools and also, to a considerable extent, the old fashioned self-hardening tools (such as Mushet) when run at their 'economical' or ' standard' speeds, pass through the following characteristic phases . . . The line of the cutting edge, which is at first keen, becomes very slightly dull so that it shines when held in the light, and it is then gradually rounded over until it finally loses all resemblance to a cutting edge, and after severe use frequently looks as if it had been purposely rounded over'.

This account by a meticulous observer suggests that the plastic deformation of the edge in our tests was characteristic of tool behaviour when cutting wrought iron. The ability of carbon steel tools to cut wrought iron, even at these low speeds depends on the strain hardening of the tool as it deforms. Figure 9 shows stress vs plastic strain curves for a hardened 1% C steel and were compression tests on small cylinders of steel, step-loaded at increasing stress at four temperatures. The yield flow stress decreased rapidly as the temperature increased from 20 to 400°C, particularly above 200°C. At all temperatures considerable strain-hardening was measured and, even at 400°C, the yield flow stress more than doubled from 500 to 1200 MPa (32 to 78 tons/in^2). This strain-hardening was a factor which made possible continued cutting, after quite severe edge deformation, without sudden catastrophic failure.

Clearly the stresses involved were of the order of 1200 to 1500 MPa (80 to 100 tons/in^2) and, where the tool surface temperature reached 400°C layers were sheared away (Figure 5). This set a definite upper limit to the speed which could be used. 19th century machinists, by empirical methods, found the shapes of tools (eg round-nosed tools with an optimum rake angle) which would enable the feed to be increased and which, together with the use of coolants, made possible the maximum rate of metal removal with carbon steel tools.

Using all their skills, the upper limits to the rate of metal removal were very low, and machining was very costly and slow. Carbon tool steels and their heat treatment had been part of conventional technology for more than 2000 years. Crucible steel melting had greatly improved the uniformity and cleanliness of the steel, and this must have improved performance by enabling the tool edge to withstand more deformation without local fracture. By controlling accurately the carbon content and keeping sulphur and phosphorus to a minimum, chemical analysis had further improved consistency. The crucible process had made possible the introduction of new alloying elements, but it was not until 1868 that the steel making craftsmanship of Robert Mushet resulted in tools with improved metal cutting properties. The addition of tungsten and manganese or chromium resulted in air-hardening tools which could be used to machine steel and wrought iron at rather higher cutting speeds. It is a reasonable assumption that the higher speeds were achieved because the elevated temperature yield stress of the tool steel was higher, reducing edge deformation of the tools.

The major development came only after heat treatment was modified by Taylor and White in the years 1898 – 1900[2]. They discovered that, if high tungsten, chromium steels are hardened from a temperature near the melting point – about 1200°C – and tempered about 560°C, they were capable of cutting wrought iron and steel at speeds of 100 ft/min or higher. As a result of this heat treatment high speed steel retains its strength to much higher temperature than carbon steel as shown by the dashed lines in Figure 9. As with carbon steel, the high speed steels are greatly strengthened by the first few percent of plastic strain. The yield flow stress is considerably higher than that of carbon steel even at room temperature. At 400°C the yield stress at 3% strain is more than three times as high, and even at 600°C it is nearly twice as high as that of carbon steel at 400°C.

Wrought iron and many steels can be machined using high speed steel tools at speeds as high as 100 to 150 ft/min, where the temperature of the tool edge is 600 to 650°C, with only minor plastic deformation of the tool edge. It was precipitation strengthening of the martensite, the first major industrial use of precipitation hardening, which made possible the great revolution in machine shop practice which resulted from the introduction of high speed steel.

References

1 J W E Littlewood, Engineering, 1901, Dec 27, p 882.

2 F W Taylor, Trans A S M E, 1907, **26**, 31.

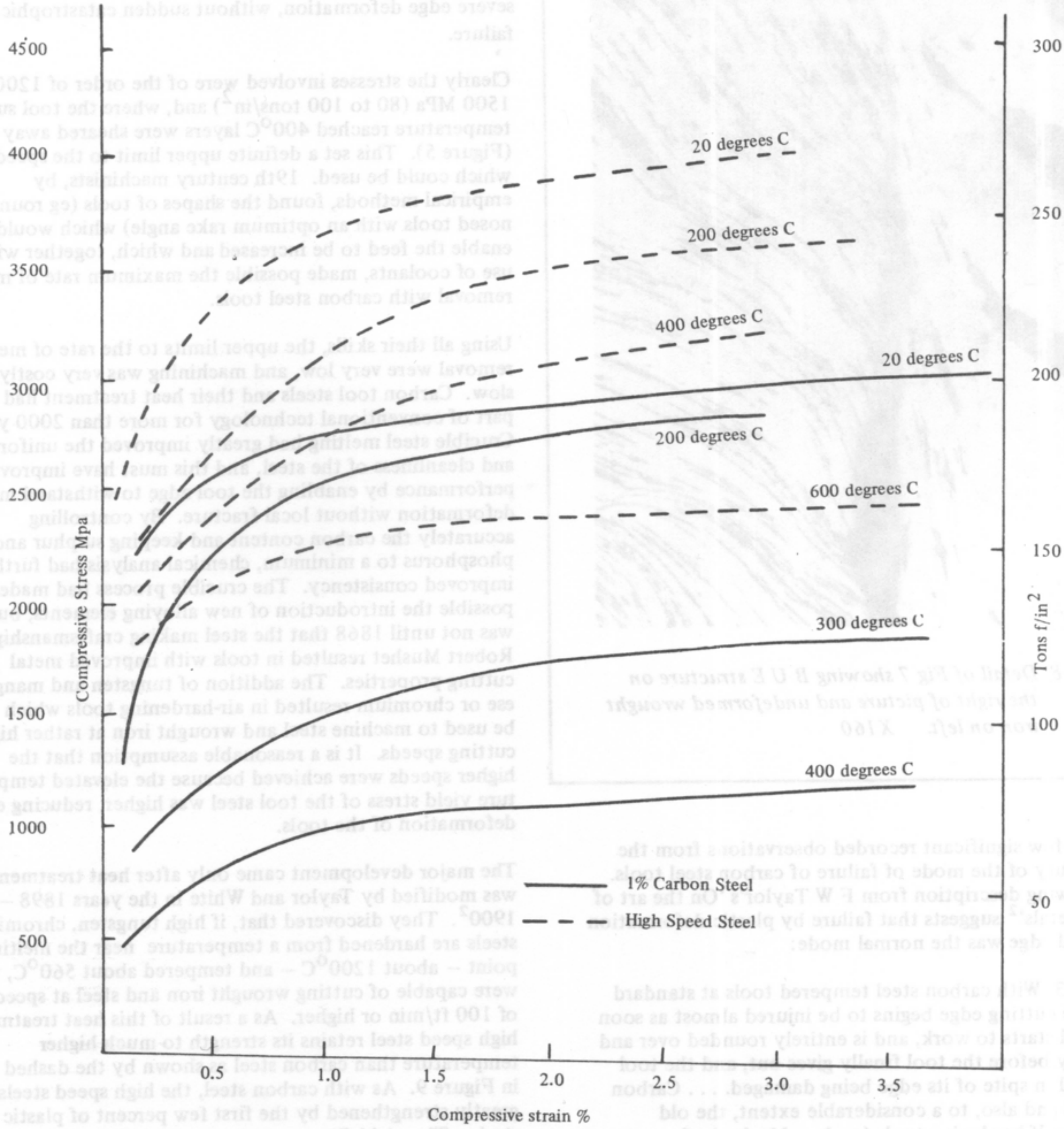


Fig 9 Stress vs Plastic Strain in compression tests on 1% C steel, Hardened, and High speed Steel, hardened and tempered

Acknowledgments

The authors are grateful to the City of Birmingham Museum for permitting them to examine the Boulton and Watt cutting tool used in this work and to remove parts of the tool for use in the experimental work. They are also grateful to the SS Great Britain Project for supplying the wrought iron bar used in the cutting tests.

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Studies on an ancient Chinese cast-iron object with a bronze coating

W Rostoker, B Bronson and J Dvorak

Abstract

Metallographic examination of an ancient Chinese object in the form of a flat-bottomed cup shows it to be of cast iron with a copper-rich alloy coating. The copper alloy is of a high tin content and contains some lead. Experiments were performed to duplicate the process of coating and the structure which develops at the surface. The functional purposes of such a casting are discussed with the view of pointing out how simple shapes can be used for multiple applications.

Of the authors, Rostoker is with the University of Illinois at Chicago; Bronson is with the Field Museum of Natural History in Chicago; and Dvorak is with the Brunswick Corporation in Fond-du-Lac, Wisconsin.

Introduction

The Field Museum of Natural History in Chicago possesses a varied collection of Chinese cast iron objects, dating as early as the Warring States period (475-221 BC) and as late as the Ming period (1368-1644 AD). Most of these objects were acquired by Berthold Laufer, a member of the Museum staff, in the course of two extended trips to China – one in 1908/1910 and a second in 1923. Some of these objects – plaques, statues and bells – served decorative and ceremonial purposes; but the majority obviously had more utilitarian functions – farm implements, cooking braziers, oil lamps, cooking bowls and pans. The widespread recovery of similar objects from recent tomb excavations has established that mass production of utilitarian items was on-going by at least the Han period (206 BC - 220 AD). Cast iron production figures do not exist for the early periods but by 1000 AD they were in the several thousands of tons per year[1]. Mass production casting procedures using baked clay stack moulds and cast iron permanent moulds were both in use as early as the Han period[2,3,9].

Two of the objects in the Field Museum collection are thick-walled, flat-bottomed, cup-shaped pieces of no obvious artistic qualities. One is illustrated by the photograph in Figure 1. Both pieces are heavily encrusted with rust so their true dimensions can only be approximated as: 8.5 cm OD; 7.2 cm external height; 0.9 cm wall. They were recovered from a grave in Shanxi province and acquired by Laufer during his first expedition. The Museum records identify them as chariot naves; ie caps which fitted over the axle ends to prevent the wheels from coming off. Laufer assigned their age as probably from the Han period. While a shape such as that shown could serve the stated purpose, there are no transverse holes by which to pin the naves to the axle. That at least some actual wheel naves made provision for the cross holes are shown in the diagram for the stack mould casting product serving the same purpose illustrated in Figure 2.

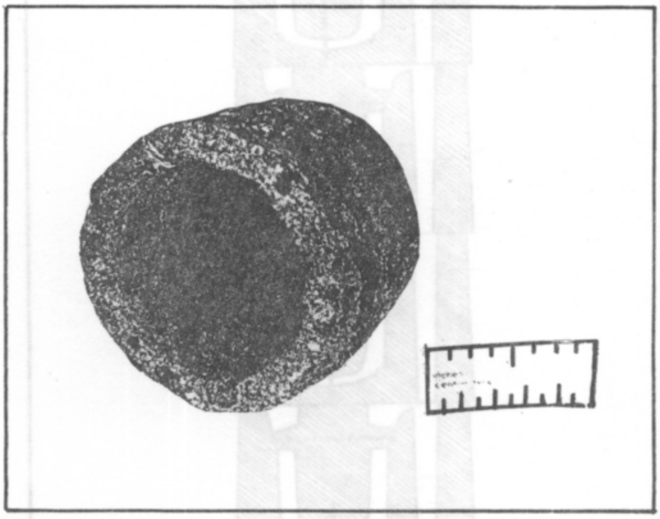

Fig 1 *Photograph of the flat-bottomed, cast iron cup-shaped object identified in the Field Museum collection by the code: FM 120999A. Note that FM 120999B is a companion object which appears superficially to be identical and was recovered at the same time.*

Two objects, apparently identical to those in the Field Museum, were observed by one of us (WR 1981), in the Honan Provincial Museum, Zhengchao, PRC. In the same case were a spear head, a saw, a sickle and several hoes. All were identified as cast iron objects belonging to the Warring States period. The dating was based on other finds made at the two excavation sites in the environs of Zhengchao. The two objects were identified as mortars, presumably used with a pestle to grind to powder medicines, herbs or spices. The curator of the exhibit, however, without commenting on the labelled identification, expressed the opinion that they were tamper heads of a type affixed to the end of wooden posts for pounding clay floors and fortification walls. It is curious that such a simple shape should elicit such varied explanations. Perhaps just because it is a simple shape, it could fulfill a variety of functions.

The idea of the metal-tipped tamper is illustrated in Figure 3 from Needham[4]. In discussing road building, Needham[5] comments: '. . . rubble and gravel tamped down in the manner of pise walls . . .' Further, translation from a Han dynasty document ascribed to Chhien Han Shu reads: 'The road was made very thick and firm at the edge and tamped with metal rammers'. The artist who created Figure 3 gave the metal tip a bullet-shaped nose which does not seem functional. For the consolidation of clay, gravel and rubble, a flat-headed tip would be more appropriate. There is the same difficulty with illustrations of tilt- and trip-hammer tips used for hulling and grinding grain as reproduced by Needham, Fig 359, 617[5]. Again these tips are domed or pointed rather than flat headed which only makes them quite inefficient even if the mortar had a matching curvature. In these very old illustrations we may often assume that the artist had taken liberties or perhaps had never really seen what he was drawing. What we should be able to agree upon is that practical people anywhere would arrive empirically at similar basic designs for pounding, crushing and grinding tools.

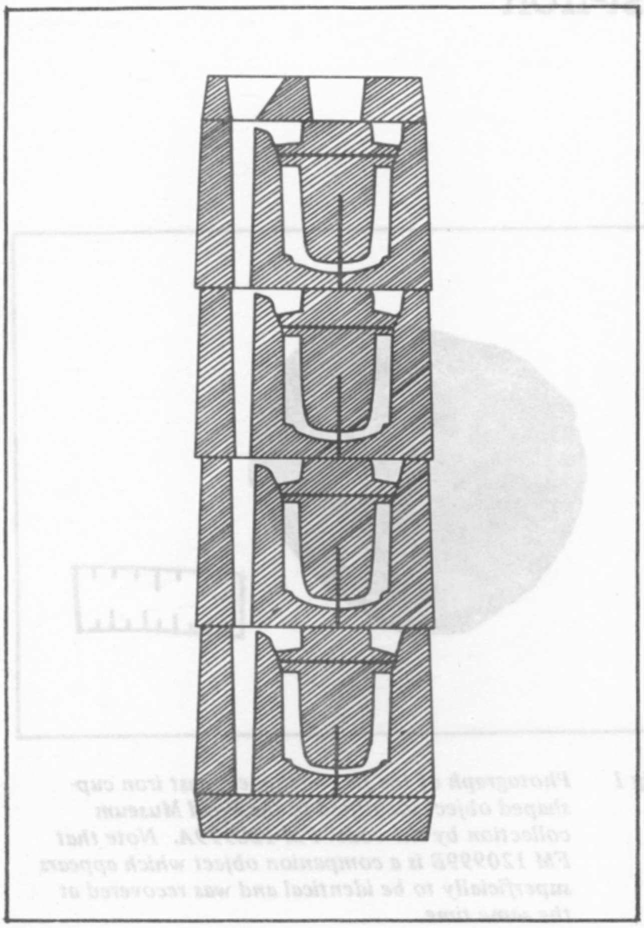

Fig 2 Adaptation from the illustration of the stack mould assembly for the production of a chariot nave given in 'Han Period Stack Mould Casting . . .', 1978

We already have three interpretations of the function of this object. It is not idle guessing to consider other options. For example, we might consider application to the horizontal water wheel with its vertical shaft as illustrated by Needham, Figures 461, 582, 602, 621[5]. Although the drive shaft must rest in some way on the stream or river bed, no details are shown, see Figure 4. Obviously there must have been an end bearing; otherwise the wood shaft would have been pulverized at the point of contact with the bed of the stream. The cast iron object of Figure 1 would serve this purpose well if it articulated with a heavy rock in a natural or cut recess. It serves in the same manner as the bearing for a heavy door. The tamper rod application can be extended to uses as sledge hammer heads for quarrying and mining before the advent of the full head as a casting. This trend of fitting tips to wood shafts shows in many early farm tools such as ploughs; it evolved later to full integral castings[3]. The point of this discussion is that none of these applications are mutually exclusive. Minor variants of a simple shape are easily accommodated by casting technology, so that multiple uses would naturally proliferate as the product became available irrespective of the original intent.

Metallographic Examination

A very small specimen was removed by two cuts with an abrasive disc in a V-configuration (visible in Figure 1) so that the thickness of the wall at the rim was represented. A micrograph at low magnification (x100) is shown in Figure 5. While the graphite obviously identifies the material as a cast iron, the shapes and sizes of the graphite particles are not very typical, being a mixture of short, ragged flakes and small spheroids. The observations are further complicated by comparably sized pockets of rust. It is interpreted that this casting solidifed as a mottled iron (a mixture of grey and white iron). The casting then experienced a thermal cycle sufficient to develop a malleablized structure; hence the graphite nodules. The

Fig 3 An ancient illustration of the use of a tamper to pound (densify) clay floors and walls reproduced in Needham et al, 1971; 39.

metal matrix is mostly pearlitic with some hypoeutectoid ferrite. At higher magnification, and in the unetched condition, graphite flakes near the surface have an envelope of copper-colored phase. See Figure 6. At the surface itself, there is the discontinuous residue of a coating with some complexity of microstructure.

An enlarged micrograph of the surface zone in the unetched condition is provided as Figure 7. The coating has two phases – a light copper-colored matrix and a darker, dendritic phase. The copper-colored phase has penetrated into the cast iron structure and enveloped some of the graphite flakes. By the use of energy dispersive analysis by X-

Fig 4 *Drawing from an 18th century manuscript showing a horizontal water wheel with a vertical drive shaft as reproduced from Needham and Wang, 1965; 208.*

radiation, the two phases have been analysed as follows. The light copper-colored phase shows (numbers rounded off): 57% Cu, 38% Sn, 5% Pb. The darker dendritic phase shows: 93.5% Fe, 1.7% Cu, 1% Sn, 0.5% Pb, 1.9% Si. At this point, the surface microstructure gives the appearance of a Cu-Sn-Pb alloy having been fused on to the surface of the mottled iron casting at a sufficiently high temperature and for a sufficiently long time to have dissociated the massive carbide to graphite and for the liquid alloy to have dissolved a substantial amount of iron. The penetration of the copper alloy ahead of the dissolution front is secondary to the liquid dissolution of iron and on cooling to the precipitation of iron-carbon alloy in the form of dendrites. This part of the story is quite common in the copper brazing of carbon steels[6].

Some Replicating Experiments

Contemporary experience with wetting copper and copper alloys to cast irons is found under the subject of brazing[7]. This is not an easy process. Whereas liquid copper and its alloys readily wet and spread over the surface of a carbon steel, the presence of graphite in the structure seriously reduces wettability. Figure 8 shows a sessile drop angle of about 67° when liquid copper is melted in a reducing atmosphere on a grey iron block. Contemporary technology recommends preparatory surface treatments of grey and malleable iron which include: abrasive blasting with steel shot, or oxidizing the surface and then reducing it.

Using a block of simple grey iron cut into slices, some experiments have been performed to establish conditions for wetting and diffusion/dissolution by a copper alloy. The alloy was the composition given by the EDAX analysis of the copper matrix on the coating of the ancient cast iron object, ie 57% Cu, 38% Sn, 5% Pb. The experiments were performed in sealed crucibles containing the cast iron slice in a horizontal position upon which rested a piece of the copper alloy with some graphite powder to ensure a somewhat reducing atmosphere.

Wetting was achieved by pre-oxidizing the cast iron surface lightly. Presumably the oxidiation to an opaque film of iron oxide ensures the absence of a film of graphite on the cast iron surface which would surely prevent wetting by molten copper alloy. A coating was achieved by heating to 890°C for 1.5 hours. The coating had many of the attributes of the ancient object.

Figure 9 shows the coating/cast iron interface. The molten coating has dissolved the iron between the graphite flakes leaving the latter projecting into the liquid metal. There has been some penetration by the liquid along the flakes into the undissolved cast iron but it does not show well in black-and-white prints. Figure 10 shows the iron dendrite/copper alloy matrix character of the coating which compares favourably with Figure 7. We are now reasonably assured that diffusion coating of cast iron with a tin-rich copper alloy is technically feasible and that the interface structure is essentially that seen on the ancient object. The reason for the high-tin copper alloy is to produce a coating at a temperature well below the solidus temperature of the cast iron itself. The choice of 890°C for the coating temperature is not far above the liquidus temperature of the Cu-Sn-Pb alloy[8].

Discussion

While all of the functions postulated for this cast iron object are reasonable, the existence of a low-melting

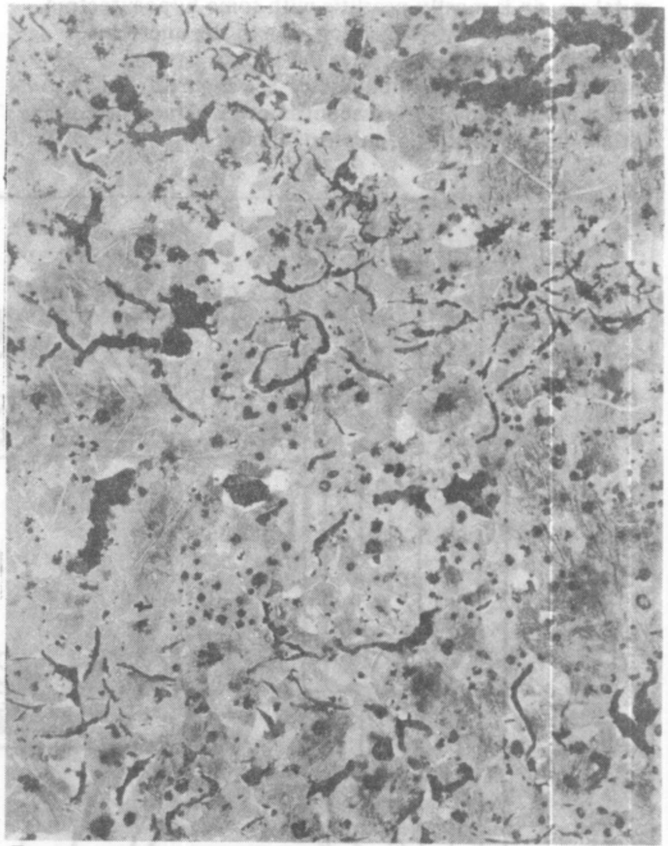

Fig 5 *Micrograph (x100) showing the graphite particles distributed in a pearlitic matrix which is the sub-surface structure of the cast iron object shown in Fig 1.*

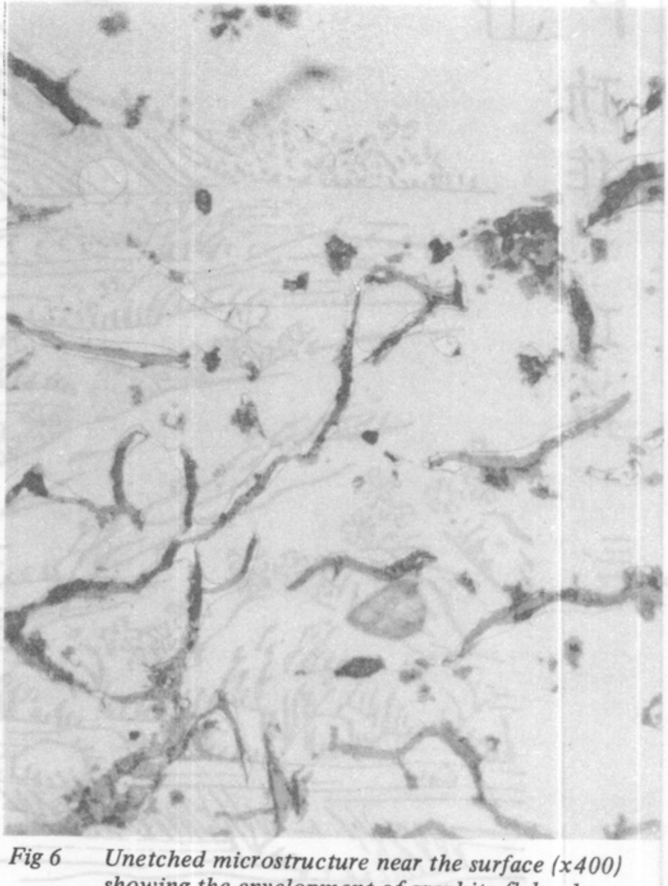

Fig 6 *Unetched microstructure near the surface (x400) showing the envelopment of graphite flakes by a light phase (copper colour under the microscope).*

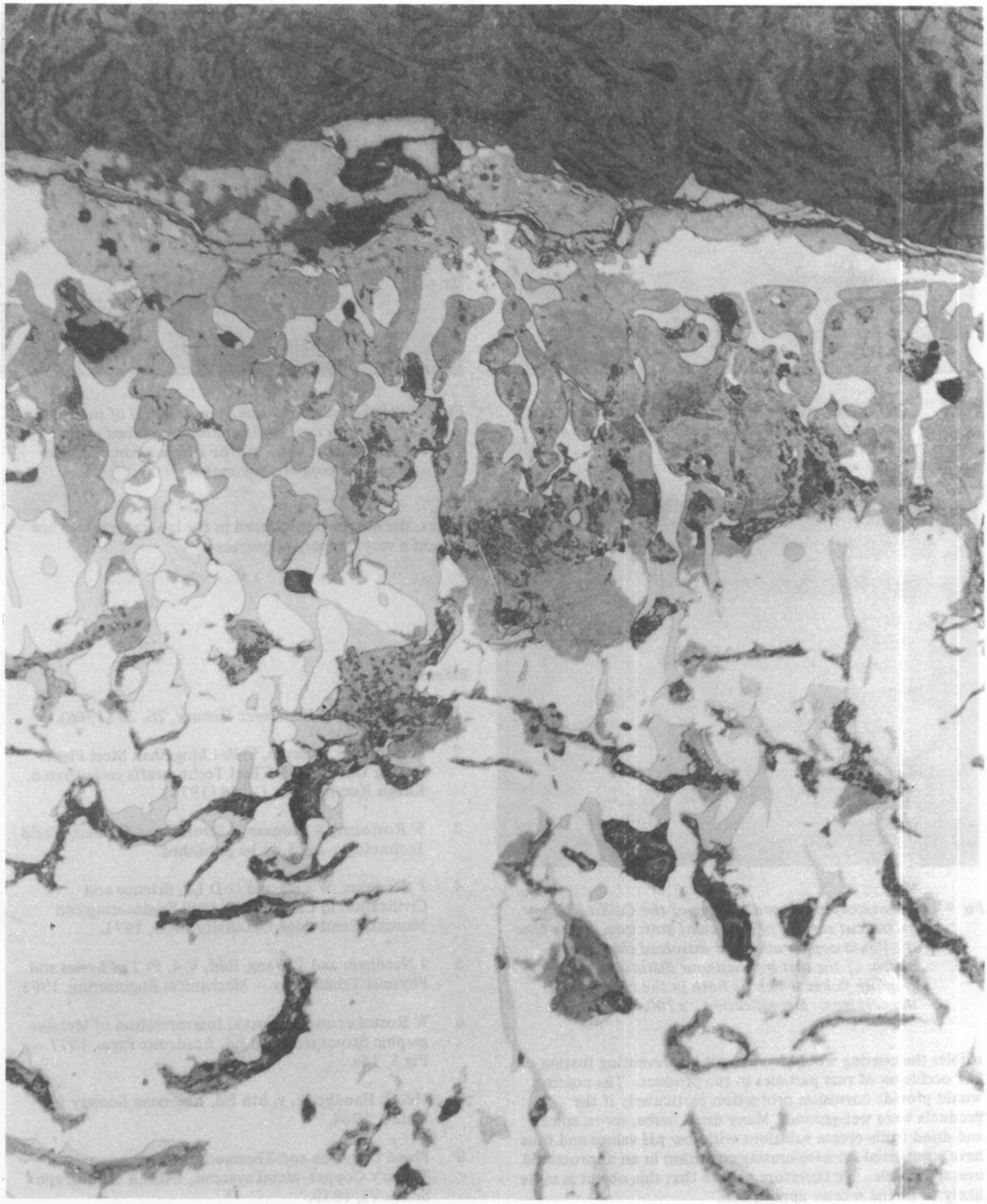

Fig 7 *Enlarged micrograph (to ca x1000) showing the copper alloy coating and the penetration into the cast iron substrate. The alloyed iron dentrites are dark grey; the surrounding lighter matrix is light grey; and the unchanged cast iron metal matrix is white. The deeper penetration of the coppery phase along the graphite flakes can also be seen.*

copper alloy as a coating must be factored into the decision. Such applications as tamper and hammer heads would not benefit from the coating. If the cup were fitted tightly to the drive shaft of a horizontal water wheel, the non-heat-treated mottled iron would provide more wear resistance than the copper. On the other hand, in an application such as a mortar for grinding medicines and

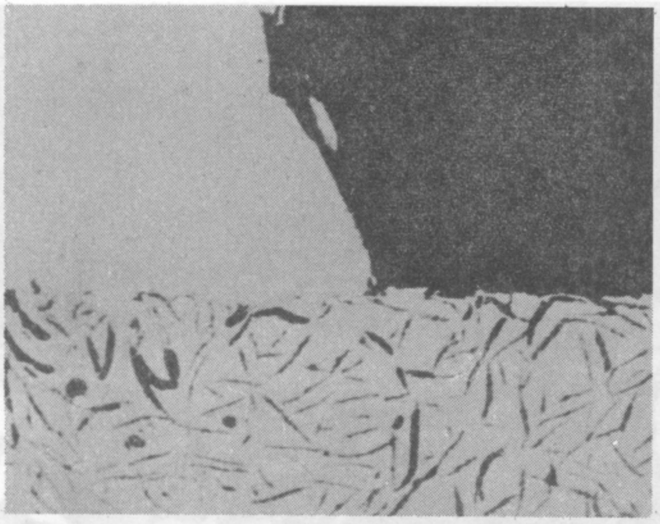

Fig 8 Section through a sessile drop of bronze on a grey iron surface produced in a reducing atmosphere at 950°C.

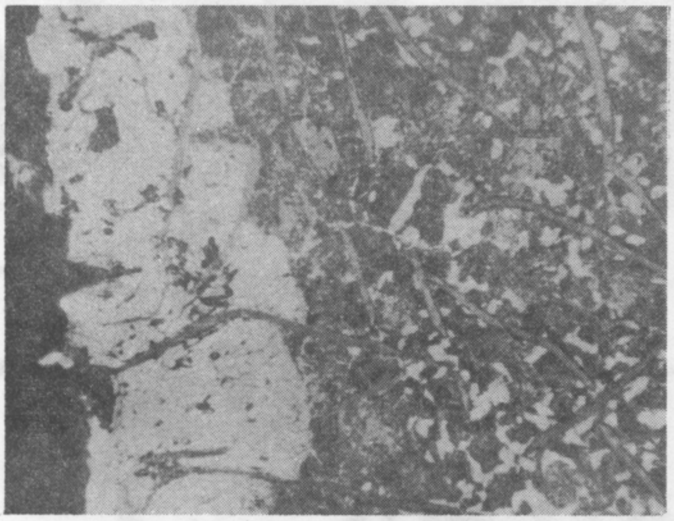

Fig 9 Laboratory-produced coating of the Cu-Sn-Pb alloy on the cut surface of a piece of grey iron. Note how the liquid copper alloy has dissolved the metal matrix of the cast iron without disturbing the graphite flakes which lie both in the coating and the cast iron. Magnification: x200.

edibles the coating would have merit in preventing rusting and occlusion of rust particles in the product. The coating would provide corrosion protection particularly if the products were wet-ground. Many dried herbs, roots, spices and dried fruits create solutions with low pH values and thus have a potential for accelerating corrosion in an unprotected iron receptacle. We therefore believe that this object is more likely to fit the mortar application.

The use of the very high tin content fits the need to conduct the wetting and coating process at a temperature well below the solidus of the cast iron. The small lead content is not rational in a contemporary sense but it has been a common minor component of bronze alloys almost everywhere throughout history. We rule out the copper alloy coating for purely decorative purposes because, from a simple visual aspect, the coating reproduced in the laboratory does not present a very coppery appearance.

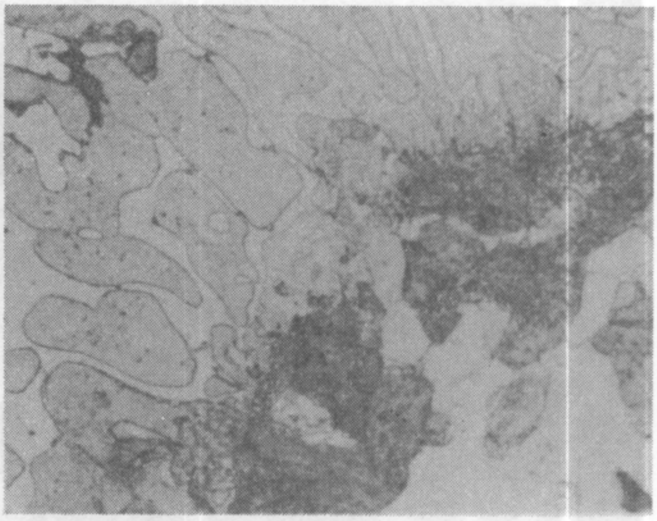

Fig 10 Higher magnification view (x1000) of the solidification structure in the coating produced in the laboratory; showing the alloyed iron dendrites and the copper alloy matrix.

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Some traditional Chinese iron production techniques practiced in the 20th century

Donald B Wagner

Some siderurgical techniques of surprising antiquity survived in China well into the twentieth century. They have been documented by competent engineers, and this documentation can provide a technical basis for the study of ancient written sources and archaeological material.

The traditional techniques varied greatly from region to region in China, and one cannot speak, for example, of 'the' Chinese blast furnace. Each region's techniques must be studied separately. In this article I shall give a survey of some of the many Chinese regional techniques, concentrating on those for which I have found good illustrations. The pictures will do most of the talking here; detailed technical information is available for most of the techniques, but much careful study will be required before I am in a position to describe them properly.

Figure 1 shows a blast furnace in the province of Sichuan, photographed in about 1935[1]. Obviously it is not in blast, and I do not know how old it is. It could be very old.

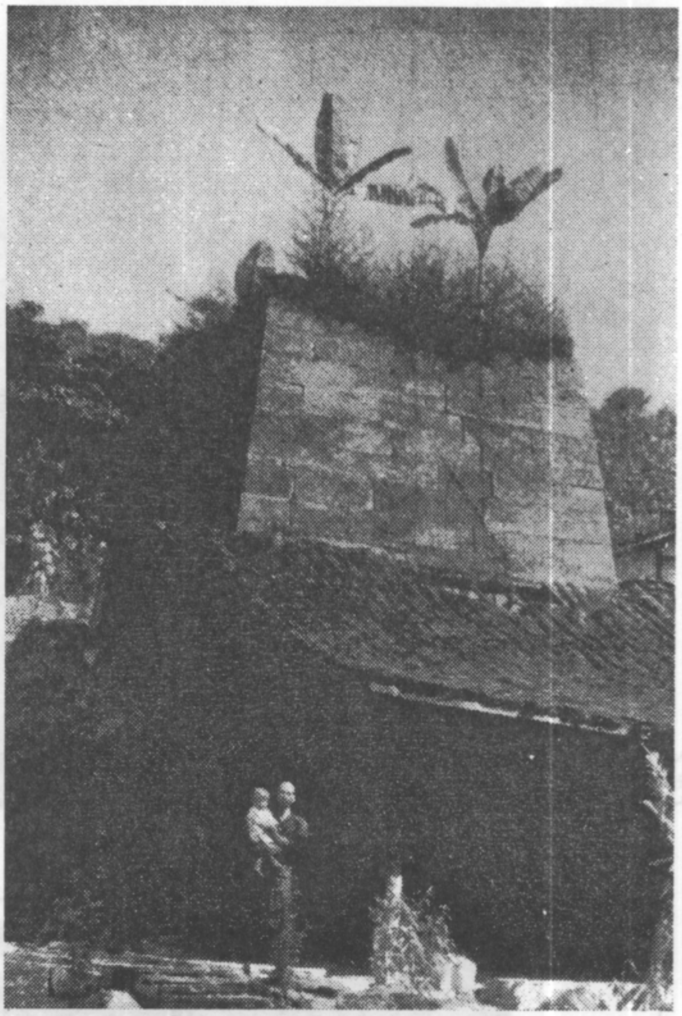
In 1958, in connection with the Great Leap Forward, a campaign was started to increase steel production by the establishment of hundreds of thousands of small ironworks using the traditional techniques of each region (see eg McFarquhar[2]). In connection with this campaign a great many technical studies were published, and these are excellent sources for the traditional Chinese techniques. Figure 2 shows a row of traditional-style blast furnaces in the province of Hunan in 1958[3]. This is the same type of furnace as in Figure 1, except that it is faced with timber rather than stone. Such furnaces consisted of an inner shaft of sandstone or firebrick, an outer wooden or stone frame, and a layer of pounded sandy clay between the two[4].

Another type of blast furnace used in Hunan, photographed about 1900, is shown in Figure 3. The furnaces in Figure 2 used charcoal as the fuel, but this one used coke[5]. It seems similar to a blast furnace illustrated in the seventeenth-century technological encyclopedia **Tian gong kaiwu** ('The products of Heaven and Man', first edition 1637). This latter illustration has been reproduced so often in Western works that it need not be repeated here (see eg Sun & Sun[6] and Needham[7]).

Notice in Figure 3 the 'windbox', or double-acting piston bellows, which supplies the blast. By the use of an ingenious system of valves it provides blast on both strokes of the piston. Here one man works the windbox, but for some types of blast furnace two, four, or even six were needed.

Figure 4 shows a blast furnace in the province of Gansu, photographed in 1958[3].Gansu is far off in the northwest of China, and I have found no further information on this type of furnace. It has a number of interesting features, for example the semicircular brick wall at the very narrow mouth. What purpose did it serve?

In the provinces along the southeast coast of China a type of blast furnace called a 'trumpet furnace' was widely used. Its normal use was in smelting ironsand, and the trumpet form of the furnace was necessary in order to reduce the pressure of the top-gas so that ironsand was not blown out.



圖二　冶鐵爐全景　*Fig 1*

The ironsand was very carefully washed, and generally contained about 90% iron oxides. There was so little gangue that no flux was needed in the smelting process. Figure 5 shows such a furnace, not in China but in the Philippine Islands in 1902[8]. It was undoubtedly brought here by Chinese immigrants from southeast China. However in the Philippines it was used for smelting ore gathered from surface outcrops; no flux was used, and the loss of iron to the slag was about 20%.

A similar type of blast furnace is shown in Figure 6, and will be seen again in Figure 13. These are watercolours (I have unfortunately not seen them in colour) from an album of twelve by an unknown Chinese artist, preserved in the Bibliotheque Nationale in Paris ('Fer', C.E. Oe 119 in-4°); (cf Huard & Wong[9]). They are reproduced here by permission. Mme Madeleine Barbin, Conservateur de la Reserve, has kindly informed me that the album is one of a collection acquired in China by the **Mission Lagrene,** a diplomatic and commercial mission which spent about a year in Guangzhou (Canton) in 1844-5. The history of the

Fig 2

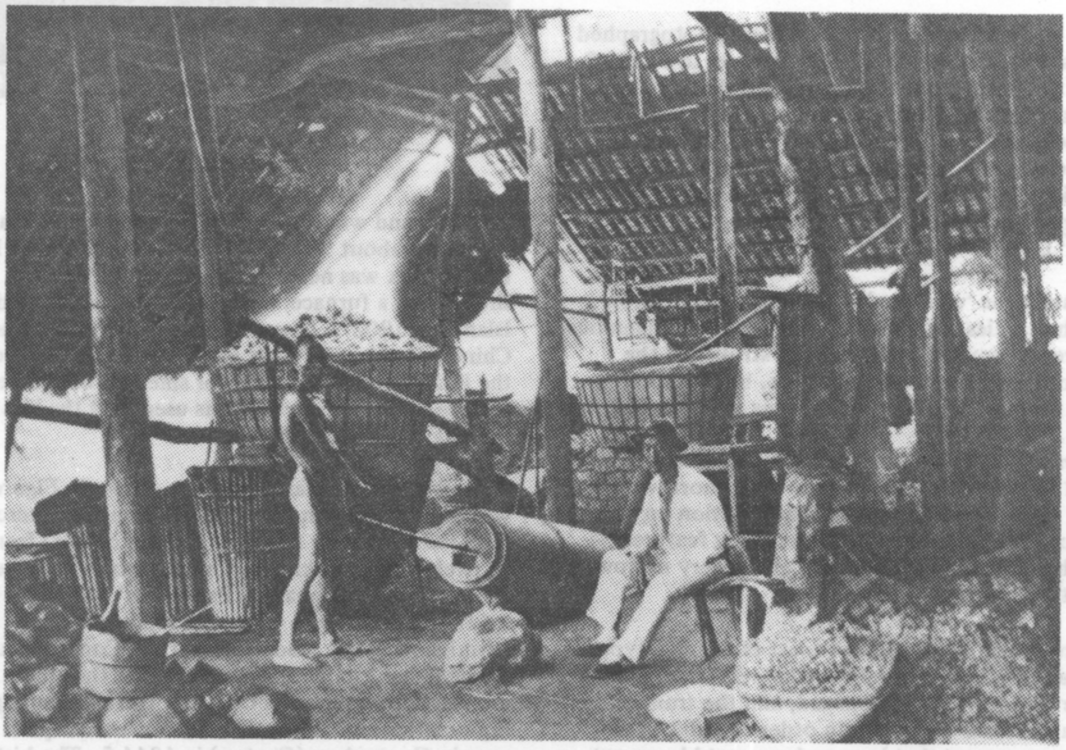


Fig 3

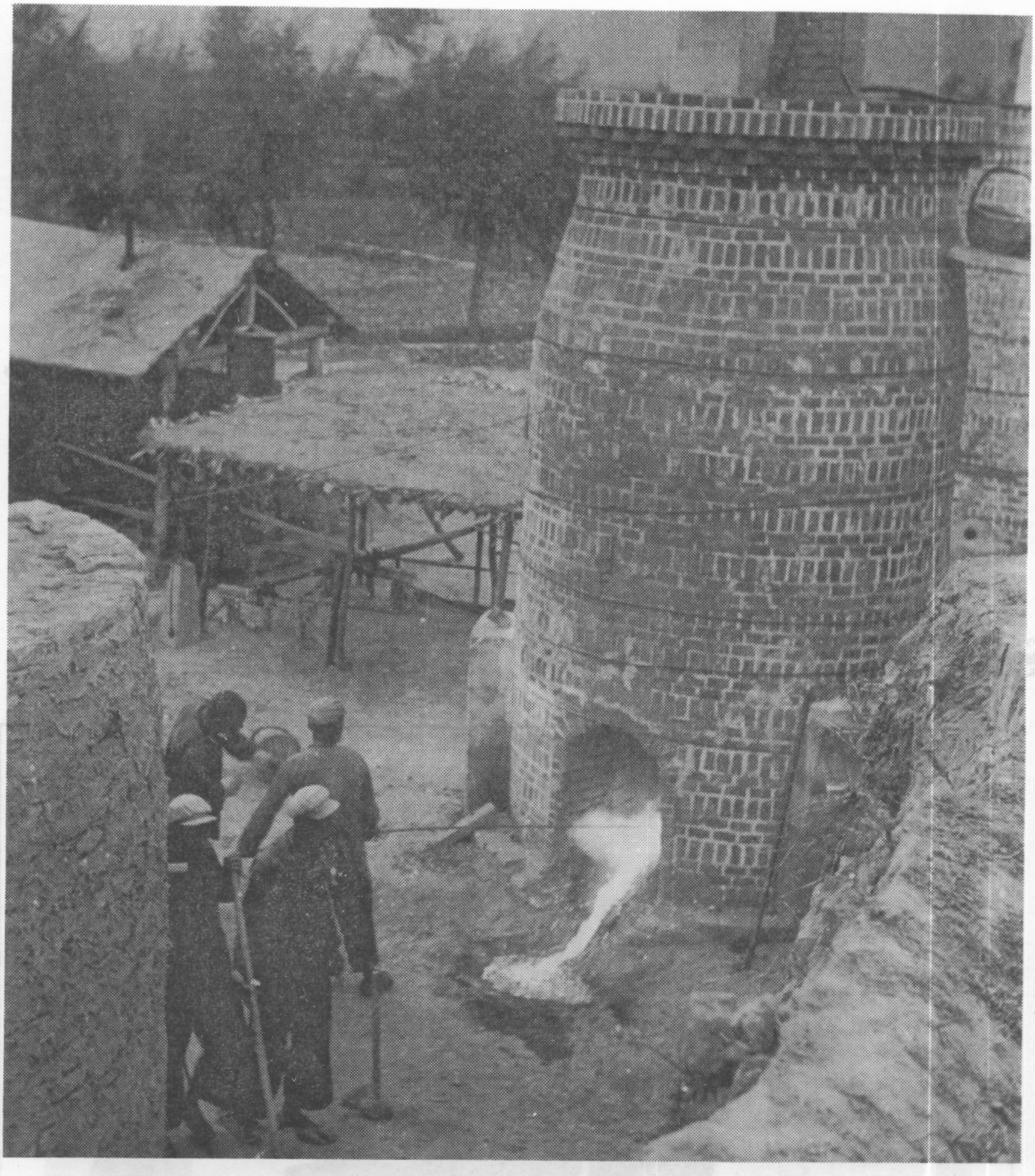


Fig 4

mission is described by Lavollee[10], who also gives a long bibliography of books and articles by members of the mission (pp 415-17). In a look through a small part of this material I have not found any information about the album, but there is still hope that more searching will reveal something. The watercolours were undoubtedly painted in Guangzhou, where many artists mass-produced pictures, the 'postcards' of the time, for sale to Europeans. They probably show a type of blast furnace used in the province of Guangdong, though the possibility cannot be ignored that the artist copied some older drawing from somewhere else.

It is obvious that the artist has taken great liberties here. The windbox is much too small, and it is being worked with one hand by a man squatting in a position which does not allow him to exert much strength. The idea of standing on a stool to charge a blast furnace is difficult to accept. How far shall we go in accepting the details of the furnace itself?

Fig 5

It is at least possible that the furnace is quite accurately depicted: the artist may have had a chance to see and sketch it when it was out of blast, and then put workers into his picture as fantasy and considerations of composition dictated. The trumpet of the furnace was probably of china clay (kaolin), shaped by plastering it on the inside of a plaited form. This would account for the appearance of wickerwork on the trumpet.

So far I have shown some of the largest and some of the smallest types of blast furnace. Figure 7 shows one of intermediate size, perhaps 3-4 m tall, photographed in 1958[11]. I do not know where it was photographed.

I have considered in the above some types of blast furnace for which I have been able to find pictures. One more, for which I unfortunately do not have a picture, is so remarkable that it must be mentioned: a blast furnace only 30 cm in height. It resembled a water bucket. The inside diameter was 10 cm at the mouth, 16 cm at the boshes, and 13 cm in the hearth. Production was 20-25 kg per day. This type of furnace was traditionally used in Echeng County, Hubei, and apparently nowhere else. On the eve of China's national day, October 1, in 1958 there were 62,544 of these furnaces in blast in Echeng County, with a total daily production of 1500 tons of pig iron[4].

I hope that the above has convinced the reader that traditional Chinese siderurgical technology was a many-splendoured thing. The techniques of each region must be studied separately. In a forthcoming book[12] I have studied the traditional iron industry of the Dabieshan Mountains. This is a rugged isolated region about the size of Denmark which comprises parts of the provinces of Henan, Hubei,

Fig 6

and Anhui. It was estimated in 1917 that in the northern (Henan) part of the region 100 ironworks produced annually a total of 14,000 tons of pig and bar iron. In the following I shall outline the principal aspects of the iron industry of the Dabieshan Mountains, still letting the illustrations tell most of the story. For more details and complete documentation the interested reader is referred to the above-mentioned book.

Charcoal. Charcoal was produced by hundreds of families living in the mountains. Each had a small carefully-managed forest, sold firewood and charcoal to the peasants and ironmasters in the valleys, and apparently lived on this production without engaging in agriculture. The charcoal was made in 'kilns', but details are not available. They may have resembled the charcoal kiln shown in Figure 8, in the vicinity of Beijing in about 1838[13]. The diameter of this type of kiln could be up to 4 m, the depth up to 1.8 m.

Ironsand. The ore used was ironsand. The washing of ironsand was a sideline production of the peasants in the valleys; it is shown in Figure 9, photographed in Xinyang, Henan, by the Swedish geologist, E G Nystrom in about 1917[14]. An analysis of the washed ironsand in 1958 indicates 65% iron: ca 70% Fe_3O_4, 20% Fe_2O_3, and 5.5% SiO_2. This is so pure that no flux is needed in smelting it.

The blast furnace. Figure 10 shows the blast furnace, again by Nystrom in about 1917[14]. There is a single taphole for both iron and slag; to tap the iron the whole furnace was tilted. The chain which can be seen is apparently a safety measure; it limits the tilt of the furnace. The furnace was tapped about twice per hour.

Figure 11 is a diagram of essentially the same type of furnace, from a technical study at a people's commune in Macheng, Hubei, in 1959[15]. Dimensions are given in 'market inches' (**shicun**, 3.3 cm). It was constructed by what amounts to 'potter's methods' of a mixture of 30% loess soil and 70% sand; lined with a mixture of 70% loess and 30% powdered charcoal; and reinforced on the outside with wrought-iron bands.

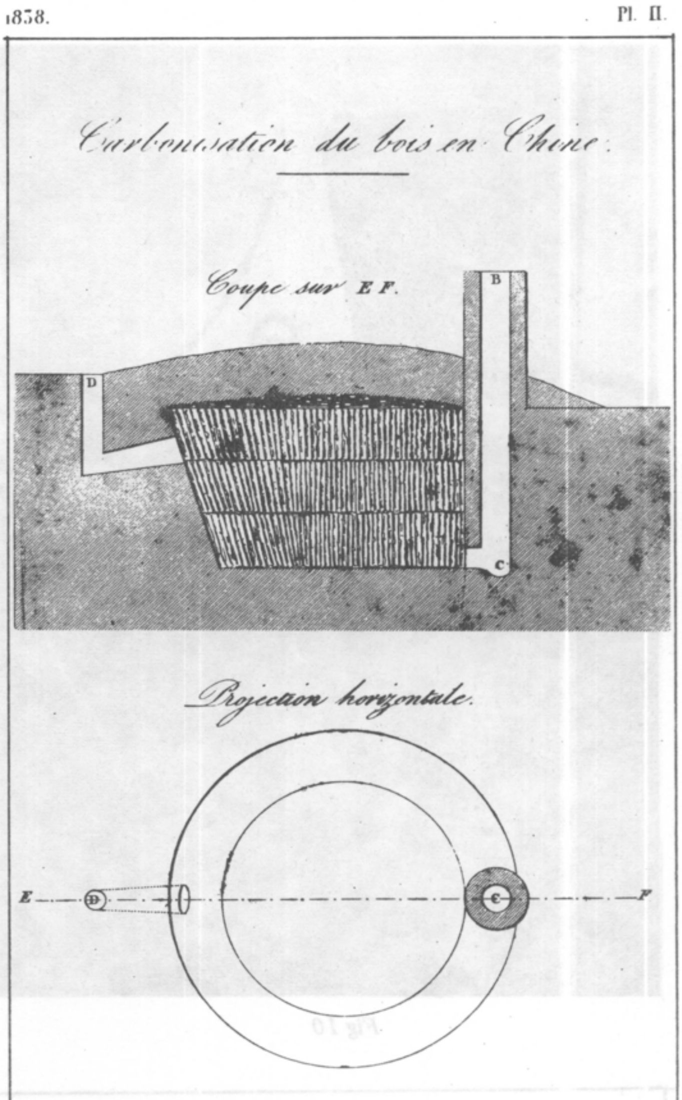


Fig 8

Fig 7

Fig 9

Fig 10

Fig 12

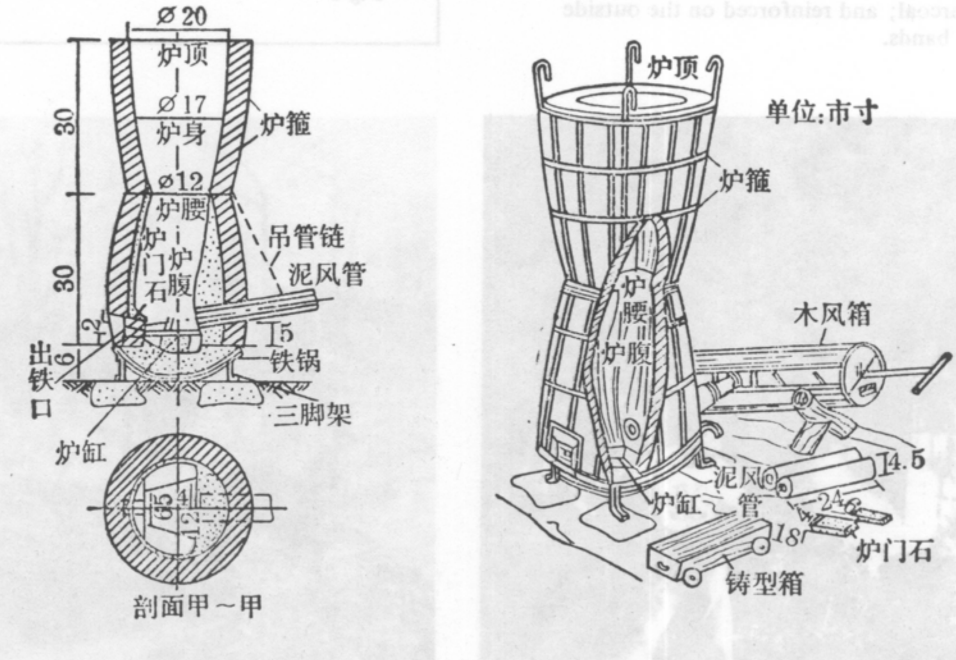


插图 52 湖北省麻城县的甑炉
(采自«冶金报»1958 年第 45 期)

Fig 11

The bottom was made of three woks. 'Wok' is the most common English word for the round-bottomed braising pan used in Chinese cooking: the worker in Figure 10 is holding one. The traditional wok is of cast iron, with diameter 40-60 cm or more and wall-thickness as little as 1 mm. Cast-iron woks are still being produced in China, but today spun-steel woks are much more common.

The part of the furnace which was subjected to the highest temperatures is the area around the taphole. It was made of sandstone or diatomaceous earth. This is the only material used which was not available locally; it was necessary to buy it from places farther south.

In this particular furnace (Figure 11) the inputs to produce 1 kg of pig iron were 1.1 kg charcoal and 1.5 kg wet ironsand. In some other furnaces of the same type used in the Dabieshan region twice as much charcoal was charged, but a large part left the furnace unburnt in the slag and was recycled. This use of excess charcoal apparently improved the permeability of the furnace burden. It seems to have been important to charge the ironsand wet; the vaporization of the water helped to spread out the grains of the ironsand.

Figure 12 shows the tapping of a similar blast furnace in Anhui, photographed in 1958[11]. Here a cross-beam functions in the same way as the chain in Figure 10 to limit the tilt.

Another conception of how such a furnace might be tilted is shown in Figure 13, another charming watercolour from the same album as Figure 6. I wonder whether such a primitive and dangerous procedure was ever actually used. Perhaps the artist knew only that the furnace was tilted for tapping, and had to imagine for himself how this was done.

The pig iron from the furnace was cast into plates with dimensions ca 50 x 12 x 1 cm. Figure 14 shows a cartload of these plates, photographed in Anhui in 1958[3]. Analysis of a sample of the pig iron in 1958 indicated:

C	Si	Mn	P	S
4.2%	0.2%	0.25%	0.3%	0.03%

Some of the pig iron was used by foundries, but most was converted to wrought iron.

The converting hearth. The method used for converting pig iron to wrought iron is often referred to as 'puddling' and sometimes as 'fining'. The process is however considerably different from either of these early Western methods, and I shall here refer to it as 'converting'. The Chinese word is **chao**, whose basic meaning is 'stir-frying', one of the basic methods in Chinese cooking.

Figure 15 is a diagram of the converting hearth[15]. It was in essence a small hole in the ground, 40-50 cm deep, with a clay cover, protected and insulated by a 'nest' of piled-up earth. Blast was blown in at the top, and a small opening was provided for the insertion of an iron bar to stir up the charge of fuel and pig iron. Figure 16 shows the operation of a somewhat similar converting hearth, photographed in the province of Shanxi in 1958[16].

The hearth was charged with 7 kg wood, 7 kg charcoal, and

Fig 13

Fig 14

70 kg broken-up pig iron. The fuel was ignited and allowed to burn with a high blast for 20 minutes: then the charge was stirred about ('stir-fried') vigorously for another 20 minutes; finally the iron was taken out a little at a time and hammered on an anvil to remove slag. Two men took turns at the wind-box which supplied the blast, two worked at the furnace, and two did the hammering.

The product was small iron bars, about 3 x 3 x 11 cm. Analysis of a sample in 1958 gave:

C	Si	Mn	P	S
0.1%	0.1%	0.06%	0.2%	0.003%

Figure 17, photographed in Hunan in 1958 [11], shows some similar wrought-iron bars.

Archaeological and metallographic evidence indicates with considerable certainty that essentially the same converting process was used in China as early as the first century BC. The Chinese word for the process, **chao**, is also used to translate the English word 'puddling', and this usage has led to some cofusion. Some Chinese writers believe that Henry Cort's invention of 1783 was anticipated in China 18 centuries before. Considering what we otherwise know of ancient Chinese technical accomplishments this would hardly be unbelievable; however the process described above is clearly closer to fining than to puddling. The essential feature of puddling is that the fuel is separated from the iron in a reverberatory furnace, so that coal can be used; furthermore the iron is molten through the greater part of the process. In the Chinese process described above the iron is never molten, and is in direct contact with the fuel, so that coal cannot be used.

In parts of China where it was necessary to use coal as the

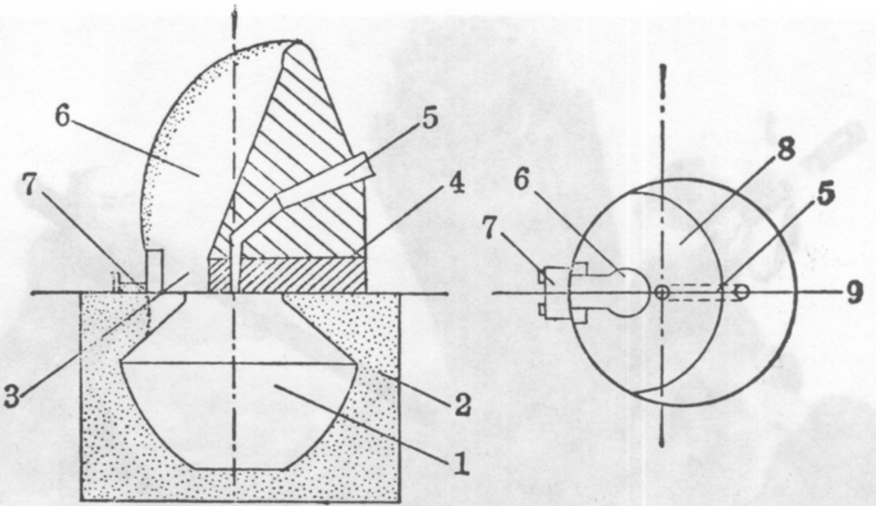


插图 60 河南省商城县土法炒钢炉的正视图和剖视图

（采自冶金工业出版社编«土铁土法炼钢» 1958 年 10 月版，

第一篇«河南商城县的土法低温炼钢»）

部位名称：1.炉缸 2.夯实的耐火泥 3.炉门口 4.天门盖 5.通风管

6.炉门 7.炉门铁 8.炉窝 9.地面

Fig 15

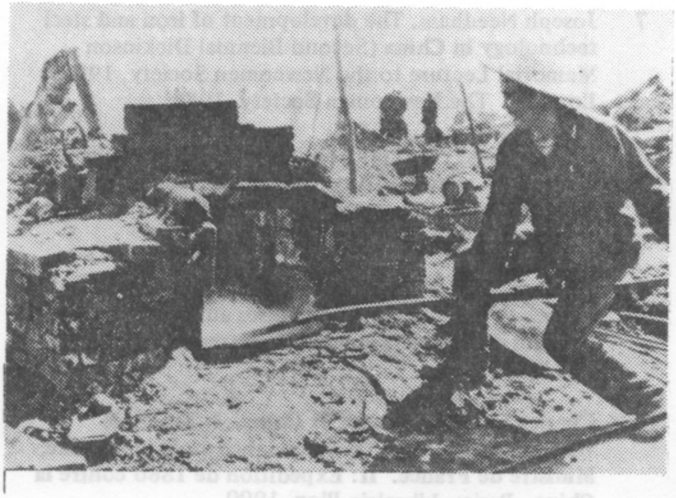


Fig 10

fuel a somewhat different converting hearth was used. One of many variations, used in Sichuan in about 1935, is diagrammed in Figure 18[1]. Coal was burned in the upper chamber, **a**. Blast was blown in through the passage **c** from the windbox at the upper left. The flame travelled through the passage **d** to the hearth **b**, where the iron was stirred about, probably in the molten state.

Converting in this latter type of hearth seems much closer to puddling. I know of no evidence as to when it was invented, but it is quite possible that it has been in use for many centuries. If this turns out to be the case, one might well be inclined to agree that Cort's invention was anticipated in China: but arguments about this question will concern definitions of terms, and will not be very interesting.

More interesting is the fact that both the blast furnace and the converting hearth were invented in China before the Christian era. and nothing like either one was used in the West for well over a thousand years. Furthermore, though unassailable proof is not yet available, both probably came to the West from China rather than being independently invented.

I suggested at the beginning of this article that a detailed study of the twentieth-century traditional Chinese techniques can provide a technical basis for the interpretation of ancient written sources and archaeological material. A few words in conclusion may clarify what I mean by this. Early writers on Chinese metallurgy, paralyzed by the idea of 'unchanging' China, tended to believe that the techniques which could be seen in use in China had been used since the dim past without variation. In recent years we have been forced to see the folly of this view. We have learned that we must look carefully for reliable sources that can indicate when and where the techniques were invented, and how they have changed over the time. We must also be careful not to assume without evidence that the twentieth-century techniques represent the high point of China's technological development.

Study of the construction and operation of blast furnaces like those in Figures 1-7 above will not tell us **directly** how the Han-dynasty blast furnaces (on which see eg Tylecote [17]) were constructed and operated. It must be expected that a great deal has happened in blast-furnace design in the past twenty centuries. Nevertheless the interpretation of the archaeological remains is impossible without some technical background, and studies of the traditional Chinese blast furnaces will clearly provide more realistic background than our knowledge of modern blast furnaces.

Fig 17

Ongoing research of mine seems to be leading to the conclusion that the Chinese iron industry reached a peak in both technical sophistication and tonnage output in the eighteenth century. The nineteenth century and the early twentieth were a bad time for China; I need only mention four apocalyptic factors: explosive population growth, epidemic spread of the opium habit, civil war, and foreign aggression. The iron industry suffered in addition from competition with cheap foreign iron. Every ship from Europe to China needed a ballast; in the early years of the China trade those that did not carry opium carried lead, but in time, as the number of ships in the trade increased, the lead market was glutted and the more usual ballast cargo was iron. This was generally scrap, for example old horseshoes, sold off cheaply to make room for a homeward cargo of tea. It was an excellent material for Chinese smiths, who

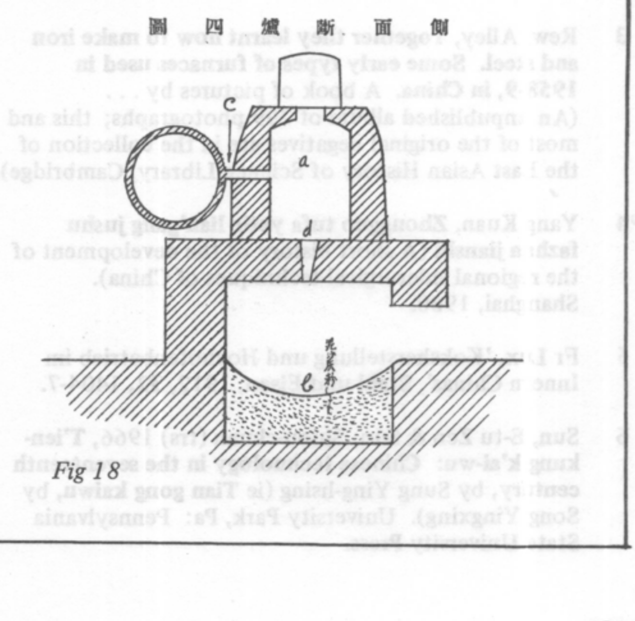


Fig 18

were accustomed to working with small bars like those shown in Figure 17.

By the twentieth century the Chinese iron industry was a shadow of its former self. Foreign competition had depressed prices to the point that profits were almost nil. The depression of prices was exacerbated by the fact that the Chinese industry usually could compete only in price, not in quality. Technologically the first casualty was the most advanced techniques, those of large highly capitalized works which produced high-quality bar iron for large markets. Large markets required good transportation facilities, and thus were the most easily penetrated by foreign competition. Large capital outlays require high profits, and as profits declined proto-capitalists merchants shifted out of iron into more profitable industries. The traditional industry survived best in isolated regions like the Dabieshan Mountains, where transportation was poor, wages were low, and the techniques were labour-intensive rather than capital-intensive.

Thus the twentieth-century techniques, for which we have detailed documentation, cannot be expected to be fully representative of the older techniques. Two examples are the use of water power and the use of coke in smelting. It appears certain that both were widely used as early as the tenth century AD, and quite possibly many centuries earlier; but there is very little evidence of either in the twentieth-century iron industry.

This article is part of a study financed by the Danish Research Council for the Humanities. I am indebted to Mr Charles Blick and Prof R F Tylecote for encouraging me to expand my lecturette for the HMS Conference, September 1983, into an article for the journal.

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Biography

Donald B Wagner holds degrees in mathematics and Chinese, and has studied metallurgy at the Technical University of Denmark. He is presently a research fellow under the Danish Research Council for the Humanities.

Elemental analysis of Himalayan metal statues

P Nieuwenhuysen & F Adams

Abstract

Elemental analyses have been performed of 23 Himalayan metal statues belonging to the collection of the Ethnographic Museum of Antwerp, most of them dating from the 19th (and 18th) century.

The elemental composition of samples from the base were determined by analysing the (scanning) electron beam induced X-ray fluorescence using an energy-dispersive detector.

Besides Cu, the following elements were detected in one or more of the statues: Zn ($\leqslant$ 40%), Sn ($\leqslant$ 1.8%), Pb ($\leqslant$ 2.2%), Fe ($\leqslant$ 1.8%), Ni ($\leqslant$ 0.6%), and Bi; these measured concentrations are well contained within the ranges covered by reported analyses of other Himalayan statues. The Zn concentration was between 22% and 32% in 13 statues and $\leqslant$ 2% in 5 statues. The concentration of Sn was lower than that of Zn; in other words, the statues were made of copper or brass and not of bronze. Of the 13 statues that were completely gilded, 9 contain less than 0.2% Pb, while 4 of the 6 ungilded statues contain more than 0.2% Pb; this indicates that most of the makers knew that Pb in the alloy is injurious to fire-gilding, while the presence of Pb has technical advantages also (eg lower melting point of the alloy, higher fluidity of the melt).

Introduction

The elemental composition of samples taken from 23 metal statues from the Himalaya-region (Nepal, Tibet, part of China) has been determined by (scanning) electron probe microanalysis. The objects belong to the collection of the Ethnographic Museum of Antwerp, Belgium (Dr A Claerhout, adj conservator). Most of them date from the 19th century ($\geqslant$ 13) and from the 18th century ($\geqslant$ 5).

The aim of these analyses was to determine the types of alloy used. The results form a useful addition to the iconographical, stylistic and other technical considerations regarding metal statues from different times and regions.

Atomic absorption analyses have already been reported for 37 metal Buddha statues older than the 17th century[1] of antique Indo-Tibetan metal statues including 2 gilded Tibetan statues of the 19th century[2], and for more than 120 Himalayan metal objects, most of them belonging to the collection of the British Museum[3]. At the time of writing this article, we received also the report of the elemental analysis by optical emission spectrometry of 89 Himalayan objects of the Musée Guimet (Paris)[4].

The present paper shows that electron probe microanalysis is a suitable alternative for the determination of constituents in metallic art objects. In addition to the bulk analysis, the method provides useful information on homogeneity and surface segregation for a number of elements.

Method

One sample was taken from the inner side of the base of each statue. This was embedded in condufix (iron-acrylate), polished fine to 1 μ m and investigated with an electron-microprobe (Jeol 733 Superprobe) operating at typically 25 kV. This allowed firstly the inspection of the sample surface by light microscopy and by scanning electron microscopy using secondary electrons and back-scattered electrons. Subsequently the elemental composition was determined by analysing the scanning electron beam induced X-ray fluorescence with an energy dispersive detection system (Tracor Northern, TN-2000) (eg, Heinrich[5]). From the measured X-ray spectra, the intensities of the characteristic X-rays were derived and from these the elemental concentrations were calculated, by using a fast standardless analysis program which incorporates a ZAF procedure (Tracor Northern). The accuracy of the analysis was tested by analysing repeatedly a brass standard (NBS-1108) from the National Bureau of Standards (Washington DC, USA), by comparison with an independent wavelength dispersive detector and software, and by independently deriving X-ray intensities from the displayed spectra; because the X-ray peaks characteristic for Zn and Cu are not completely resolved, a correction for spectral interference was always incorporated.

The scanning electron microprobe allows the selection of the sample area to be analysed, so that heterogeneities can detected and the analysis of fragments that have suffered from corrosion can be avoided; moreover, as the region analysed is shallow, the surface region of the artifacts can be compared with deeper subsurface regions. Furthermore, the analysis is non-destructive, and the sample can be preserved. Moreover, the energy-dispersive analysis of the X-ray fluorescence allows the simultaneous detection of a large number of elements, including also unexpected ones. These are advantages in comparison with atomic absorption analysis which necessitates dissolution and a separate analytical scrutiny for each element to be determined. On the other hand, atomic absorption analysis has a higher sensitivity, but this seems not essential for this study.

Results and discussion

Photographs of four of the statues analysed are shown in Plate I.

A brief description of every statue and of the elemental composition determined is given in Table 1. All samples contained copper and one or more of the following elements:

Zn ($\leqslant$40%), Sn ($\leqslant$ 1.8%), Pb ($\leqslant$ 2.2%), Fe ($\leqslant$ 1.8%), Ni ($\leqslant$ 0.6%) and Bi (detected only in the globules).

These concentration ranges are well contained within those found for Himalayan metal statues belonging to the collection of the British Museum[3] and of the Musée Guimet[4] Silver nor gold were detected in any object; this agrees also with other analyses [1-4] which revealed only very exceptionally silver or gold concentrations higher than 0.2%.

A first inspection of Figure 1 shows that the zinc content of 5 samples is $\leqslant$ 2%, 12 contain between 22% and 32% and only 6 fall outside these ranges.

Table 1 : Elemental Analyses of Himalayan Metal Statues

Identification Number	Origin	Dating	Height in cm	Gilding[a]	Cu	Zn	Sn	Pb	Fe	Ni
55.44.2[b]	Nepal	19th cent	27	+	99 ± 1	≤ 2	≤ 0.3[b]	≤ 0.2	≤ 0.2	≤ 0.2
57.4.12	China (Beijing?)	± 1760	16.5	±	76 ± 1	23 ± 1	≤ 0.3	≤ 0.2	0.6 ± 0.1	≤ 0.2
57.4.14	N E Tibet	± 1850	20	–	70 ± 1	29 ± 1	≤ 0.3	≤ 0.2	1.0 ± 0.1	≤ 0.2
57.4.16	Tibet	1800-1850	16.3	±	69 ± 1	30 ± 1	0.3 ± 0.1	≤ 0.3 ± 0.2	0.3 ± 0.1	≤ 0.2
57.4.18	Nepal	18th cent	17.4	–	69 ± 1	31 ± 1	≤ 0.3	≤ 0.2	0.3 ± 0.1	≤ 0.2
57.14.2	Nepal	early 19th cent	16.5	+	73 ± 1	22.5 ± 0.5	1.5 ± 0.1	1.5 ± 0.4	1.0 ± 0.1	0.5 ± 0.1
57.14.4	China	± 1850	23	+	75 ± 1	23 ± 1	0.4 ± 0.1	≤ 0.2	0.8 ± 0.1	≤ 0.2
57.14.5	Nepal	end 19th cent	17.8	+	76 ± 1	24 ± 1	≤ 0.3	≤ 0.2	≤ 0.2	≤ 0.2
57.14.6	N E Tibet	late 19th cent	14	–	75 ± 1	22 ± 1	0.8 + 0.1	1.2 ± 0.6	0.8 ± 0.1	0.6 ± 0.1
57.14.7	N E Tibet	19th cent	10.2	–	57 ± 1	40 ± 1	≤ 0.3	1.7 ± 0.2	1.1 ± 0.1	≤ 0.2
57.14.9	China	18th cent	19.5	±	75 ± 1	24 ± 1	≤ 0.3	0.6 ± 0.3	0.4 ± 0.1	≤ 0.2
57.26.1	Tibet	?	30	+	99 ± 1	≤ 2	≤ 0.3	≤ 0.2	0.4 ± 0.2	≤ 0.2
57.26.2	S E Tibet	19th cent	15.2	+	99 ± 1	≤ 2	≤ 0.3	≤ 0.2	0.7 ± 0.2	≤ 0.2
57.26.4	S E Tibet	19th cent	11.8	+	99 ± 1	≤ 2	≤ 0.3	≤ 0.2	1.3 ± 0.1	≤ 0.2
57.28.3	Nepal	1817	15.3	+	92 ± 1	8 ± 1	≤ 0.3	≤ 0.2	0.3 ± 0.1	≤ 0.2
57.29.2	Nepal	19th cent	18.6	±	74 ± 1	26 ± 1	≤ 0.3	≤ 0.2	0.3 ± 0.1	≤ 0.2
57.29.11	Nepal	± 1880	9.4	+	67 ± 1	31 ± 1	≤ 0.3	1.2 ± 0.5	1.0 ± 0.3	≤ 0.2
59.38.2	Nepal	18th cent	10.4	+	77 ± 1	17 ± 1	1.5 ± 0.2	2.2 ± 0.2	1.8 ± 0.2	0.3 ± 0.1
59.38.3	China	18th cent	10	–	99 ± 1	≤ 2	≤ 0.3	0.6 ± 0.3	0.2 ± 0.1	≤ 0.2
60.48.7	Tibet	?	10.6	+	78 ± 1	17 ± 1	1.8 ± 0.2	1.9 ± 0.2	1.1 ± 0.1	≤ 0.2
60.48.8	China	?	16.9	±	69 ± 1	28.0 ± 0.5	0.6 ± 0.1	1.0 ± 0.2	1.5 ± 0.3	0.2 ± 0.1
60.48.9	Tibet	?	16.8	–	65 ± 1	34 ± 1	≤ 0.3	0.5 ± 0.1	0.5 ± 0.1	≤ 0.2
66.29.1-3	Tibet	?	21.9	+	94 ± 1	6 ± 1	≤ 0.3	≤ 0.2	≤ 0.2	≤ 0.2

[a] + : gilded; +: parcel-gilded; – : ungilded.

[b] Tin and bismuth were detected together in the globules.

1 *Bronze statue 57.4.12; partly gilded and with traces of blue and lead paint. Representation of Majusri, with his sakti. Probably Nepalese work from Beijing. Chinese inscriptions date the work as Qianlong (1730-1783). Height 16.5 cm.*

2 *Bronze statue 57.14.9; partly gilded. The inscription indicates it as a representation of Li-shih-t'ien. Probably Nepalese work from Beijing; Chinese inscriptions prove the production during Qianlong (1730-1783). Height 19.5 cm.*

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3 *Gilded bronze from Nepal, 57.28.3. Representation of Simhanadavalokitesvara. Date is present as Samvat 937 or A D 1817. Height 15.3 cm.*

4 *Gilded bronze from Tibet, 66.29.1-3. Representation of the dharmapala Mahakale as Gomkar. Height 21.9 cm.*

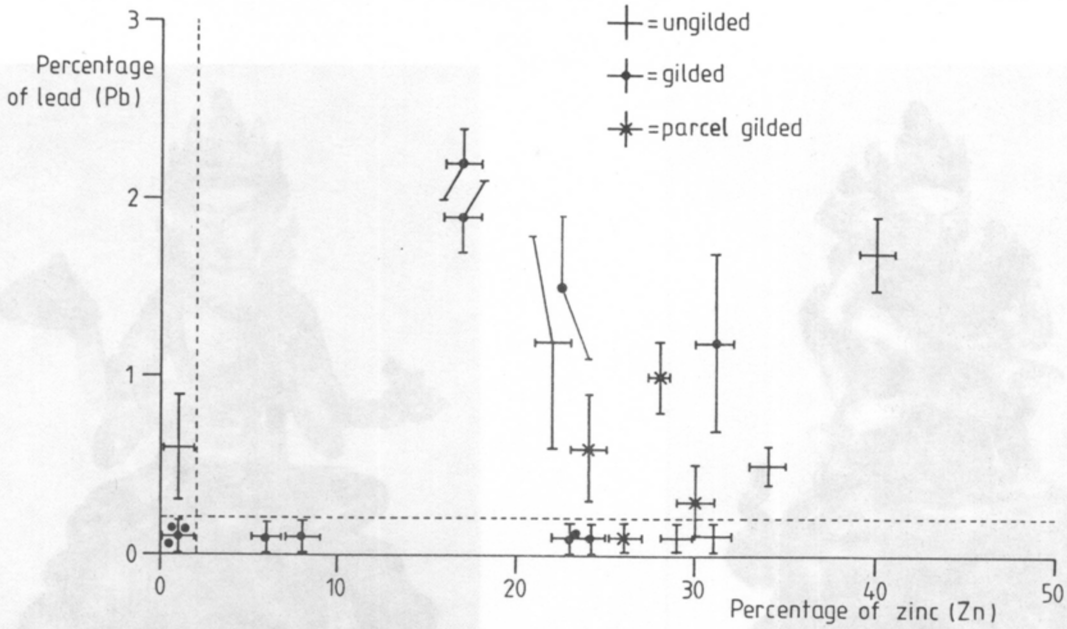

Figure 1 Lead versus zinc content measured for the Himalayan statues *The dotted lines indicate detection limits*

The concentration of tin is lower than that of zinc (Table 1); in other words copper or brass has been used in these statues and not bronze. This agrees also with the survey of Himalayan statuary in the major collections of Britain[6], with the analyses of the British Museum[3] and of the collection of the Musée Guimet[4]. 'Tin is a rare impurity in copper ores, and so some of this tin must be derived from scrap bronze or tinned copper incorporated in the melt. Some may have been deliberately introduced to facilitate the melting of copper' (Craddock)[3].

As lead is insoluble in copper at room temperature, it is present in the form of globules distributed throughout the metal, which are shown by scanning electron microscopy. The concentration of lead found in the Himalayan statues is low, relative to the values found for statues originating elsewhere (Craddock[3], p 23). From the graph of lead versus zinc content (Fig 1), it is seen that 4 of the 5 copper statues which contain less than 2% zinc, contain also less than 0.2% lead.

Furthermore, as indicated in Table 1, in none of these 5 copper statues has tin been detected. The use of such relatively pure copper poses problems for primitive metallurgy as its melting temperature is considerably higher than that of its alloys and its melt is more viscous; further, lead is and was also in the past much cheaper than copper[3]. On the other hand, the soft surface of pure copper is easier to chase than the hard and brittle surface of brass. Nevertheless there are serious drawbacks resulting from the presence of lead in copper alloys: the interface between the copper or brass and the globules of lead is a potential source of weakness, and lead in the alloy is injurious to fire-gilding[3]. It seems that the craftsmen were aware of most of these facts, as 9 of the 13 gilded statues examined contain less than 0.2% lead, while of the 6 ungilded statues examined, 4 contain more than 0.2% lead, and 5 contain more than 20% zinc (Fig 1). In accordance with the fact that lead is injurious to fire-gilding, it is observed that of the 4 gilded statues containing more than 1% lead, the 3 which have been dated (18th - 19th century) have lost most of their gold. A tendency for the fire-gilded pieces to contain less lead and zinc than the ungilded ones was also found in the study of the British Museum[7]. The modern tradition in the Himalaya seems to be also that figures for gilding are cast in almost pure copper (Lo Bue[6], p 39).

Concluding briefly, we agree with Craddock[3]: 'One can only assume that aesthetic considerations outweighed the technical'.

Acknowledgements

Dr A Claerhout, adjunct-conservator, is thanked for his advice. Excellent technical assistance was provided by R Nullens and W Vandersickel.

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Iron gun-founding in the mid 17th century The winter blowings at Horsmonden 1656 and 1659

G W E Farrow

Summary

In the Hereford County Records Office are the Foley archives, which include a section on the gunfounding accounts of the Foley/Browne/Quyntin connection 1651 to 1660. The two papers commented on here refer to the winter blowings at the Horsmonden Furnace 1656 and 1659, with details of types, weights and prices of ordnance cast.

In 1977 Major-General B P Hughes suggested to members of the Royal Artillery Historical Society that County records offices might be likely sources of artillery and ordnance material previously untapped. Herefordshire seemed an unlikely area, but Miss Jancey, then of the Hereford Office, brought to my notice a section of the Foley archives which had previously received little attention, as it referred to gunfounding 1651 to 1660, in another county area[1].

The Foleys were originally ironfounders at Stourbridge, but one branch settled at Stoke Edith in Herefordshire. When the house was destroyed by fire in 1927, the family papers were sent to the Hereford Record Office, and are available by courtesy of the present head of the family.

Thomas Foley (1617 – 1677) married Anne, the daughter of John Browne, the king's gunfounder.[2] On Browne's death in 1651, Foley as his executor took a major financial interest in the Browne establishments at least until 1660, and the papers, dating to this period, are mainly accounts submitted to Foley by Henry Quyntin (the spelling is variable), and are not complete. Among them are single sheet lists of the total pieces of ordnance cast at Horsmonden in the winter blowings of 1656 and 1659.[3]

A R Hall states that in the Weald the unit of ordnance production during the Seventeenth Century remained the small single furnace, capable of smelting about 200 tons of metal in a year, 'if we reckon 6 to 8 tons as the yield per found-day . . . and 23 to 35 found-days in a year'.[4] D W Crossley's excavations at Pippingford and Scarlets have confirmed the small size of the units[5], and these two lists bring further confirmation. (Apps 1 and 3). In 1656 245 pieces were cast, ranging from saker cutts of 8 hundredweights and 2 quarters to demi-cannon of nine feet weighing 44 hundredweights. The total weight cast was 216 tons and 11 hundredweights. There are two copies of this list, one uncosted and complete otherwise, the other costed but with an item of demi-culverins omitted. (App 1a). The totals are however both the same. No individual weights for mynion cutts of four and a half feet are given, but from the total they must have been 5 hundredweights and 2 quarters each. (The 1659 figures are 5 hundredweights only each, but Nye *(The Art of gunnery 1647)* gives the weight of 'ordinary' mynions as 750 pounds).[6] The Horsmonden mynions were however 'cutts', ie shortened. (App 1b). On the costed list for 1656, the 216 tons 11 cwts cast is given at 15 shillings per cwt, a total value of £3248. 5s. with potts remaining at the furnace on the 25th of January 1657 of 12 tons 9 cwts 1 qr at 20 shillings per cwt, in total £249. 5s. (App 2c). These two items, together with stocks remaining at Horsmonden and Bedgbury Furnaces, and Hawkhurst and Benhale (sic) Forges gives a total of £9128. 10s. (App 2).

Appendix 1. Total pieces cast at the winter blowings at Horsmonden 1656.

	Number	Weight each cwts	qrs	
Falconets	-			
Falcons	-			
Drakes	-			
Mynion cutts	40	7	0	
Mynions of 4½ ft	30	(5	2)	(b)
Mynions of 6 ft	30	10	2	
Mynions of 7 ft	-			
Saker cutts	42	8	2	
Sakers of 6 ft	-			
Sakers of 7 ft	-			
Sakers of 8 ft	12	17	0	
Demi-culverins of 6 ft	-			
Demi-culverins of 7½ ft	12	19	0	
Demi-culverins of 8 ft	16	21	0	
Demi-culverins of 10 ft	(12	28	0)	(a)
Culverins of 8 ft	-			
Culverins of 8½ ft	3	30	0	
Culverins of 10 ft	12	38	0	
Demi-cannon of 8½ ft	10	42	0	
Demi-cannon of 9 ft	26	44	0	

Total pieces:	245
Total weight:	216 tons 11 cwts at 15 shillings per cwt.
Value:	£3248. 5s.

A disbursement of £9960 on stock 'in the partnership' (presumably that of Foley and Quyntin) is certified by the auditor H D (possibly Henry Dawson) and dated 26 Jan 1657.

No list of customers is given with these figures, although a further series of accounts (16 pages)[7] shows separate transactions for 386 pieces sold 1654 to 1657, mainly for merchant ships but with 10 sakers for the service of the State delivered to Portsmouth 5 Aug 1656 and a further 10 to 'the Stores' 26 May 1657. These transactions range in size from 1 drake for Captain Jesson for the Castle frigate (19 March 1656: paid in full 23 April 1657, £5. 14s.) to a single order of 16 mynions of six feet, 12 saker cutts and 14 mynion cutts for Alder Temms and

Appendix 2. (Continuation of the information given at App 1).

Stocks remaining January 1657

	Horsmonden Furnace	**Bedgbury Furnace**	**Hawkhurst ffordge**	**Benhale fordge** (sic)
Coles remaining (loads)	401 at 30 s.	544 at 30 s.	330 at 30 s.	120 at 30 s.
costed at	£601. 10s.	£816	£495	£180
Myne (estd) (loads)	2600 at 5 s.	1600 at 4 s.	-	-
costed at	£650	£320		
Wood to ease (?) moulds (cords)	24 at 10 s.	-	-	-
costed at	£12	-	-	-
Wood for brasswork (estd) (cords)	60 at 10 s.	-		
costed at	£30	-		
Gun heads etc. Cast iron (estd) (tuns)	3 at £6	-		
costed at	£18	-	-	-
Sowes (sic) remaining (tuns)	-	78 at £6. 5s.	80 at £6. 10s.	40 at £6. 10s.
costed at	-	£487. 10s.	£520	£260
Iron remaining (tuns)	-	-	56 at £17	17 at £17
costed at	-	-	£952	£289
Totals	£1311. 10s.	£1623. 10s.	£1967	£729

Value of ordnance:	£3248. 5s.
Potts remaining:	£ 249. 5s. (c)
Stock (Horsmonden):	£1311. 10s.
(Bedgbury):	£1623. 10s.
(Hawkhurst):	£1967
(Benhale):	£ 729
Total	£9128. 10s.

Comp (?) (7 March 1655: paid in full 30 June 1655, £382). A further 6 pages gives Quyntin's disbursements for March 1656 to May 1657.[8] The pages for the early part of the full period from 1654 are missing, but there is a carry-forward figure from these pages. At the end there is a final allocation of the shared expenses. By this time Mr Foley had been paid £1260 of the total £1604 disbursed, Quyntin had taken £50 per annum attendance money for himself and his servants. The balance of £344 was shared as a debt by Foley and Quyntin.

The 1659 list (App 3) is not costed. 290 pieces were cast, weighing only 214 tons 9 cwts, but this included 50 smaller guns, falconets, falcons and drakes of between one and three hundredweights each. At the head of the list it states that the season for 1659 was of '159 days or 26 foundries 3 days of 6 days to the 'foundre' (with for the gunners 23 weeks)! Only the 1659 list shows faulty pieces, in this case 2 demi-culverin of six feet and 1 demi-cannon of eight and a half feet.

References and Notes

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2 D N B's statement that Anne was the daughter of George Brown is disproved in John Browne's will

(HRO General wills and settlements) and Thorpe's Registrum Roffense 1769, which lists the lost memorials in Horsmonden Church. The latter was brought to my notice by Anthony Cronk Esq.

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9 HRO F VI Bf 12 part 2.

The help and courtesy of Miss Hubbard and the staff of the Hereford Records Office is gratefully acknowledged.

Short Biography

G W E Farrow is a retired headmaster and a former major in the Royal Artillery. A member of the RA Historical Society and of the Society for Army Historical Research, he has a special interest in pre-regimental (pre 1716) ordnance, and has worked on the Foley gunfounding papers intermittently since 1978. He has done much indexing of artillery historical material and, among others, his indexes to the Royal Artillery Institution's military documents to to Colonel J H Leslie's historical papers, together with a concordance of the Captains Commanding Royal Artillery Companies 1716 to 1825, are in the RA Institution's library archives.

Appendix 3. Total pieces cast at the winter blowings at Horsmonden 1659.

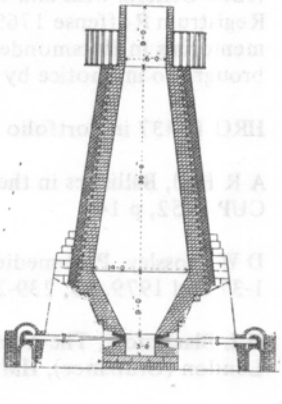
	Number	Weight each	
		cwts	qrs
Falconets	20	1	1
Falcons	20	2	0
Drakes	10	3	0
Mynion cutts	40	6	1
Mynions of 4½ ft	20	5	0
Mynions of 6 ft	-		
Mynions of 7 ft	10	14	0
Saker cutts	40	8	0
Sakers of 6 ft	20	10	0
Sakers of 7 ft	10	14	0
Sakers of 8 ft	-		
Demi-culverins of 6 ft	20	12	0 (2 faulty)
Demi-culverins of 7½ ft	-		
Demi-culverins of 8 ft	-		
Demi-culverins of 10 ft	18	30	0
Culverins of 8 ft	20	29	0
Culverins of 8½ ft	8	32	0
Culverins of 10 ft	-		
Demi-cannon of 8½ ft	34	42	0 (1 faulty)
Demi-cannon of 9 ft	-		

Total pieces: 290

Total weight: 214 tons 9 cwts uncosted.

The survival of early blast-furnaces: A world survey

David Crossley



In *HMS Newsletter No 9, 1980* The Society published a table of United Kingdom blast-furnaces sites where there are substantial visible remains. This revised a list compiled by the Historical Metallurgy Group at the very beginning of its existence *(Bulletin of the Historical Metallurgy Group 1/1 1963).* At the time when this UK list was being revised it was suggested in the Society's blast furnace committee that comparable information on overseas furnaces should also be compiled.

Over the intervening years a file of information has been gathered and refined by the author, the result of the work of numerous correspondents who have kindly shared their information. It was originally intended to print a provisional list in the *Newsletter* in 1982, and to invite comment before placing a more definitive version in the *Journal.* Due to the reduction in the size and scope of the *Newsletter,* the list has come straight to the *Journal,* delayed by the need further to clarify entries where doubts remained.

The author is well aware that inconsistencies will be found in this list. This is particularly the case where stacks are in a ruinous condition: it is hard to draw a consistent line over the inclusion of sites where a furnace is collapsing into a heap of rubble. It has been attempted to include cases where, despite the advance of decay, enough remains above ground to indicate the character of the structure and the plan-dimensions. In some instances, where rubbish has been cleared, the exposed foundation gives useful information, and a number of such cases will be found in the tables. Nevertheless, opinions will differ on whether some furnaces should have been omitted or included, and the author will be pleased to receive up-to-date information from readers familiar with structures in question. This will be published in the *Journal's* early blast-furnace notes, which will also include information on sites and, indeed, areas which it has not been possible to include here.

It remains to express thanks to all those who have assisted. They are named at the head of each national list. Many provided photographs and historical information for which there is not space here: the author welcomes enquiries as to what is available in the survey file for particular sites or areas. It is hoped that several of our contributors will be able to expand their material into articles for the journal. Any reader who wishes to be put in touch with contributors should contact the author.

Key to features:

C	Charcoal	K	Coke	A	Anthracite
W	Water-blown	H	Hot-blast		
S	Steam-blown				

Dates in brackets indicate a year when a furnace was known to be in operation.

Site Name	Area	Dates in Use First	Last	Features	Condition
Australia					
(Dr Sybil Jack John Morris)					
Fitzroy	Mittagong New South Wales	1849	1886	K S	Foundations preserved
Lal Lal	Victoria	1875	1884	C S	Furnace largely intact
Lithgow	New South Wales	1906	1930s	K S	Foundations
Tamar River (Ilfracombe Iron Co)	Tasmania	c1872/3		?K ?S	Base of furnace

Site Name	Area	Dates in Use		Features	Condition
		First	Last		
Austria					
(Dr Rainer Slotta Alex den Ouden)					
Bundschuh	Salzburg	1856	1885	C	Standing stack No lining
Edlach	Niederösterreich	1716	early 19C	C	Standing
Eisenstratten	Kärnten	1862	after 1880	C	Chimney; no stack
Heft	Kärnten	1857	1908	C	
Hirt (2)	Kärnten	after 1806	1873	C	(1 complete (1 lacks lining
Kendlbruck	Salzburg	1756	1830	C	Complete stack
Laas	Kärnten	1817	1847	C	Standing stack
Mosinzgraben	Kärnten	1768	1792	C	Complete stack
Olsa	Kärnten	1858	1870s	C	Complete stack
St Gertraud	Kärnten	1847	1883	C	Standing stack
Steinhaus	Steiermark	1840	late 1880s	C	Below top floor
Unterzeiring	Steiermark	1852-	?	C	Arches filled in
Urtl	Kärnten	early 19C	1834	C	Complete stack
Vordernberg Radwerk 3	Steiermark	1853	1921	C	Body, no stack or hearth
Vordernberg Radwerk 4	Steiermark	1846	1911	C	Complete stack
Vordernberg Radwerk 10	Steiermark	c1840	1899	C	Complete stack
Zirbitzkogel	Steiermark	1800	1871	C	Standing stack
Belgium					
(A M Terlinden)					
Fourneau-St Michel	St Hubert	1771	19C	C W	Furnace and buildings restored
Czechoslovakia					
(M Berka, J Kuba, J Merta, M Šarudyova					
Barbora	Pribram	1810	1874	C W	Standing furnace
Červeňany	Roznava	1871	1903	C S H	Restored stack
Joseph's Valley	Adamov	1732	c1870	C W	Restored stack

Site Name	Area	Dates in Use		Features	Condition
		First	**Last**		
Nižná Slaná	Rožňava	1867	1907	C W H	Preserved stack
Podbieľ	Dolný Kubín	1836	1862	C W	Partly restored
Tri Vody	Banská Bystrica	c1800	c1873	C	Preserved stack
Vlachoro	Rožňava	1870	1907	C W	Preserved stack and buildings
Finland					
(Alex den Ouden)					
Leineberg	Frederiksberg			C	
Skogby				C	
France					
(Brian Awty, Mlle A Laumon, Dr Raina Slotta, Christian Sütterlin)					
For location maps including most sites listed see C Sutterlin **La Grande Forge** (La Couarde, Ile de Re 1981)					
Ampilly-le-sec	Chatillon/Seine (Haute-Marne)	(1829)			Stone furnace in good order with surrounding buildings complete
Ans	Tourtoirac (Dordogne)	1750	1840+	C W	Twin stone furnaces in good order with fragment of iron water wheel
Apremont-sur-Aire	Granpre (Ardennes)				No information since 1961 when surviving
Banca	(Pyrénées Orient)	(1850)			Standing
Billy-sous Mangiennes	Billy (Meuse)	1780 –	1850		Intact to top-lintel level above arches. Upper stack missing
Blanquefort	(Lot et Garonne)	(1850)			Standing
Brocas	(Landes)	(1850)			Standing
Buffon	Montbart (Côte d'Or)	1768		C W	Furnace missing but surrounding buildings complete: museum project
Bure-la-Forge	Longuyon (Meurthe et Moselle)	1830 –	1873	C	Preserved stack
Champ-de-la-Pierre	Rasnes (Orne)	(1820)			Damaged
Chautay	Le Chautay (Cher)	(1860)			One side only standing: in dangerous condition

		Dates in Use				
Site Name	**Area**	**First**	**Last**	**Features**		**Condition**
Cirey	(Haute Marne)	(1820)				Base only, in a barn
Corbançon	Mezière-en-Brienne (Cher)	(1820)				Badly damaged
Cuzorn	Fumel (Lot et Garonne)	1863				Arches damaged
Derlon	Longuyon (Meurthe et Moselle)	1692 –	1859			Circular stone structure: dangerous condition
Dommartin-le-Franc	(Haute-Marne)	1820				Good condition, within building
Essarois	Aigny-le-Duc (Côte d'Or)	(1820)				Damaged
Fayolle	Jumilhac (Dordogne)	(1780)		C	W	Complete
Fontaine-Française	(Côte d'Or)	(1850)				Standing, but dangerous
Forgeneuve	Javterlhac (Dordogne)	(1750)		C	W	Twin furnaces in 18th century building: excellent condition
Forgeneuve	St-Felix-de-Reillac	(1820)		C	W	Good condition
La Granville	Cons-la-Granville (Maurthe et Moselle)	1865	1878	C		Restored
La Hardouinais	Merdrignac (Côtes du Nord)	(1820)				Good condition
Le Becquet	(Beauvaisis)	c1450 –	c1550	C	W	Fragment incorporated in former corn mill
Ivoy-le-Pre	La-Chapelle-d'Angillon (Cher)	(1850)				Parts of hearth only
Jommelieres	(Dordogne)	(1820)				Damaged: used as part of water-tank structure
Lanouée	Josselin (Dordogne)	(1820)				Standing
Limanton	Moulins-Engilbert (Nievre)	(1840)				Standing
Marcenay	(Côte d'Or)	(1820)		C	W	Under restoration
Menaucourt	(Meuse)	(1820)				Standing
La Mothe	Marthon (Charente)	(1820)				Standing
Montagney	(Haute Saône)	(1770)				In a barn: two arches missing
Le Moulinet	Saint-Front-sur Lemance (Lot et Garonne)	(1854)				Good condition
Noiron	Noiron-sur-Bèze (Côte d'Or)	(1820)				Excellent condition

Site Name	Area	Dates in Use		Features	Condition
		First	Last		
Rustrel	(Vaucluse)	1846			Two furnaces: good condition
Saint Denis	St-Denis-sur-Sarthon (Orne)	(1856)			Circular stone furnace in good condition
Saint Front	St-Front-sur-Lemance (Lot et Garonne)	(1854)			Similar to Le Moulinet. Good condition
Saint Vincent	St-Vincent-de-Mercuze (Isère)	(1850)			Furnace standing but building damaged
Savignac-Lédrier	(Dordogne)	(1820)	c1930	C W	Complete with cylinder blowers; furnace and surrounding buildings under restoration
Sommevoire	(Haute Marne)	(1842)			Complete, within modern foundry
Trécy	La Guerche (Cher)	(1855)			Survives only to 2m height
Torteron	(Cher)	(1850)			Poor condition
Val d'Osne	(Haute Marne)	(1850)			Complete: used within modern foundry as sand-loading funnel
Veuxhaulles	(Haute-Marne)	(1840)			Standing
Vendresse	(Ardennes)	(1820)			Within building
Vialette	Jumilhac (Dordogne)	(1810)		C W	Standing, but stonework poor, overgrown
Vimont	Plazac (Dordogne)	(1854)		C W	Double furnace in poor condition
Germany (West)					
(Dr Rainer Slotta, Alex den Ouden)					
Abentheuer		19th century		C W	Base of stack, with arches
Gräfenbacher Hütte		1785	1873	C W	Surviving stack
Huttenwerk	Lauchertal	19th century		C W	Preserved complex
Luisenhütte	Wocklum	1823/33		C W	Preserved complex
Wendener Hütte		1728	1866	C W	Surviving stack and buildings
Wilhelmshütte	Bornum	1738	1901	C W	Preserved stack
Zweifall-hammer	Vossenack	19th century		C W	Preserved stack

Site Name	Area	Dates in Use		Features	Condition
		First	Last		
Hungary					
(Dr Rainer Slotta)					
Miscolc-Ujmassa		c 1813			Preserved
Italy					
(J Maillet, Dr G Torraca)					
Tuscany					
Canino		1671	c1853	C W H	Furnace complete: buildings roofless; side towers survive to furnace top. Ore-roasting kiln. Fragments of trompes
Follónica		1810+		C W	Furnace within building with no access. No side towers visible. Later furnace: only front wall survives
Pescia Fiorentina	Capalbio	1618; 1699; 1776 –	c1864	C W Hafter 1847	Complete furnace with all buildings and ore-roasting kilns. Conventional furnace lines in former Bergamasque emplacement with complete towers. Trompe fragments.
Valpiana		c1800		C W	Towers survive: furnace replaced by house
Norway					
(Alex den Ouden)					
Baerum		1767 – rebuilt 1773 and 1840	1872	C	Lower stack
Feiring		1798 – rebuilt 1803-5	1818	C	Lower stack
Fossum		1790 –		C	Part of stack
Lesja		1757 –	1812	C	Half stack
Moholt		1806 –	late 1860s	C	Half stack
Mostadmarken		–	1870	C	Ruins
Naes (2)		1840s – 1840s –	1885 1910	C C	Body Base
Osen		1761 –	1781	C	Part stack

Site Name	Area	Dates in Use First	 Last	Features	Condition
Sweden					
(Dr Marie Nisser, Alex den Ouden)					
Asphyttan		16th C–	1845	C	Ruins
Avesta		1873 –	1938	C	Standing
Axmar		17th C–	1927	C	Standing: museum
Bennebol		1727 –	(rebuilt 1856-7)	C W (turbine)	Standing
Bjorneborg		(1659) 1870 –	1910	C	Blast furnace house standing
Björndammen		c 1800 – (rebuilt 1855)	1900	C	Standing
Björnhyttan		1653 –	end of 19c	C	Ruins
Borgvik		17th C –	1925	C	Ruins
Bornshyttan		16th C –	c 1815	C	Ruins
Brattfors		1835 – (rebuilt 1899)	1920	C W (turbine)	Standing
Bredsjö		1676 –	1962	C	Standing
Brevens Bruk		1864 – (rebuilt 1903)	1933	C	Standing
By		1747 –	1872	C	Part of stack
Dalfors		1726 –	1866	C	Ruins
Edsken		1644 –	1880	C	Base
Finnshyttan		(16th C) –	1876 –	C	Ruins
Flatenberg		1728 – (rebuilt 1865)	1918	C	Standing
Fogdehyttan		16th C –	1842	C	Ruins
Forsbacka		1874 –	1953	C	Standing
Gammelkroppa		16th C –	1904	C	Standing
Galtstrom		(1695) 1878 –	1916	C	Stack and part of blast furnace house
Gåsborn		1835 –	1866	C	Ruins
Gnarp		1678 –	1878	C	Ruins
Granbergsdal		1644 – (restored 1939 -42)	1929	C W (turbine)	Standing
Grythyttan		17th C –	1883	C	Lower half
Gustafsfors		1870 –	1908 (rebuilt 1880)	C	Part of stack

Site Name	Area	Dates in Use		Features	Condition
		First	Last		
Sweden					
(Dr Marie Nisser, Alex den Ouden)					
Asphyttan		16th C–	1845	C	Ruins
Avesta		1873 –	1938	C	Standing
Axmar		17th C–	1927	C	Standing: museum
Bennebol		1727 –	(rebuilt 1856-7)	C W (turbine)	Standing
Bjorneborg		(1659) 1870 –	1910	C	Blast furnace house standing
Björndammen		c 1800 – (rebuilt 1855)	1900	C	Standing
Björnhyttan		1653 –	end of 19c	C	Ruins
Borgvik		17th C –	1925	C	Ruins
Bornshyttan		16th C –	c 1815	C	Ruins
Brattfors		1835 – (rebuilt 1899)	1920	C W (turbine)	Standing
Bredsjö		1676 –	1962	C	Standing
Brevens Bruk		1864 – (rebuilt 1903)	1933	C	Standing
By		1747 –	1872	C	Part of stack
Dalfors		1726 –	1866	C	Ruins
Edsken		1644 –	1880	C	Base
Finnshyttan		(16th C) –	1876 –	C	Ruins
Flatenberg		1728 – (rebuilt 1865)	1918	C	Standing
Fogdehyttan		16th C –	1842	C	Ruins
Forsbacka		1874 –	1953	C	Standing
Gammelkroppa		16th C –	1904	C	Standing
Galtstrom		(1695) 1878 –	1916	C	Stack and part of blast furnace house
Gåsborn		1835 –	1866	C	Ruins
Gnarp		1678 –	1878	C	Ruins
Granbergsdal		1644 – (restored 1939 -42)	1929	C W (turbine)	Standing
Grythyttan		17th C –	1883	C	Lower half
Gustafsfors		1870 –	1908 (rebuilt 1880)	C	Part of stack

Site Name	Area	Dates in Use		Features	Condition
		First	Last		
Pershyttan		1856 – (rebuilt 1940)	1953	C	Standing
Rösfors		1832 –	1870s	C	Standing
Röfors		1812 – (rebuilt 1938)	1951	C	Ruins
Rönnöfors		1841 –	1880	C	Standing
Sandsjöyttan				C	Ruins
Saxån		1850s –	1909	C	Standing
Siljansfors Bruk		1738 –	1870	C	Standing
Silvhytteå		1787 –	1896	C	Stack (below top floor)
Skommarhyttan		– 1875		C	Ruins
Stålldalen		1795 –	1919	C	Standing
Storbrohyttan		1820 – (rebuilt 1850s)	1929	C	Standing
Stöpsjöhyttan		(1677) 1751 –	1882	C	Stack below top floor
Sunnemo		1860 –	1887	C	Stack below top floor
Svartå		1861 – (rebuilt 1963)	1966	C	Hearth + 80% of stack
Söderbärke		– 1855		C	Hearth
Söderfors		(1676) 1876 –	1918	C	Standing
Tjärnäs		1917 –	1882	C	Ruins
Tobo		1678 –	1925	C	Blast furnace house
Torpsbruk		1862 – end of 19th C		C	Stack below top floor
Torskebäcken		1813 – (rebuilt 1853)	1957	C	Standing
Ulvshyttan		1797 – (rebuilt 1896)	1939	C	Stack (below top floor)
Vällnora		1859 –	1890	C	Stack
Vibyjttan (= Vibyggehyttan)		Early 16th C – 1860		C	Ruins, excavated
Voxna Bruk		1726 – 1838 – 1884		C	Standing
Åg		1828 –	1927	C W	Standing
Åminne		1826 –	1934	C W	Standing
Åryd		1880s (rebuilt 1870s)		C W	Standing
Ängelsberg		1779 – (rebuilt 1878)	1919	C W	Standing

Site Name	Area	Dates in Use		Features	Condition
		First	Last		
Poland					
(Ing Jerzy Jasiuk)					
Chlewiska		1890-2	1940	C S	Restored complex
Furmonów		1830-5	1907	C W	Buildings survive without the furnace
Kuźniaki		186-	1897	C W	Stack restored; buildings incorporated
Samsonów		1813-23	1866	C W + S (after 1829)	Surviving stack and buildings
Starachowice		1899-1905	1940	C S	Restored complex and equipment
North America					
Canada					
(Richard Allen, Christopher Andreae, Arthur Dunn)					
* Hamilton	Ontario	1895	1968		Stack preserved
Londonderry	Nova Scotia	(1855	1876	C W	Base of coke furnace visible
		(1877	1962)	K S	
		1904	1908)		
** Marmora	Ontario	1822	c1839	C	Excavated
St Maurice	Quebec	1736	1883	C	Under restoration

* Modern structure

** Excavated: no standing remains

Site Name	Area	First	Last	Features	Condition
United States					
(Overall information and contacts from Eric DeLony and Robert Vogel)					
Alabama					
(James Bennett)					
Tuscaloosa County					
Tannehill		1855	1865	C	Restored and operated
Connecticut					
(Richard Allen, Victor Rolando)					
Litchfield County					
Canaan	East Canaan	1872	1923	C W	Standing

Site Name	Area	Dates in Use		Features	Condition
		First	Last		
Lime Rock		1813; 1864		C W	Standing
Sand Plain	Kent	1825; 1846; 1970	1892	C W S)	Standing
Shepaug	Roxbury	1866		C S	Standing
Wintworth	Salisbury	1810; 1845	1886	C W	Restored
Illinois					
Elizabethtown		1840	1880	C W	Restored
Maine					
(Richard Allen, Victor Rollando)					
Katahdin		1845	1890	C W	Restored
Maryland					
(Theodore Kury, Helen Schenk, Robert Vogel)					
Cecil County					
Principio	Northeast				Standing
Frederick County					
Catoctin		1857		W S	Standing (some restoration)
Worcester County					
Nassawango		1832	1848	H	Restored; heating equipment visible on top
Massachusetts					
(Richard Allen, Victor Rolando)					
Berkshire County					
Richmond		1829; 1862	1923	C W-S	Standing
Essex County					
Hammersmith	Saugus	1645	1675	C W	Restored
Norfolk County					
Winthrop	Braintree	1644	1647	C W	Stack base restored

Site Name	Area	Dates in Use		Features	Condition
		First	Last		
Michigan					
(Theodore Kury)					
Fayette		1867			Standing
Elk Rapids		1872	c1914	C S	Part-standing
Missouri					
(Theodore Kury)					
Phelps County					
Maramec	St James	1828 – rebuilt 1857	1856 1876		Standing (two) (some restoration)
New Hampshire					
(Richard Allen, Victor Rolando)					
Grafton County					
Lower Works	Franconia	1811: 1853	1884	C W	Standing
New Jersey					
(Jack Chard, Theodore Kury, Ed Rutsch)					
Atlantic County					
Actra	Head of the River	(early 19th century)		C W	Standing ruin
Monmouth County					
Allaire	Freehold	1817	1846	C W	Restored
Morris County					
Split Rock	Rockaway	1862	1863	C W	Standing
Passaic County					
Clinton	Newfoundland	1833	1837	C W	Standing
Long Pond	Hewitt	1768 1796 1862	1778) 1812) 1871(2))	(C W ((	Base excavated Part-stacks
Sussex County					
Wawayanda	Highland Lakes	1846	1856	C W	Standing
Warren County					
Oxford		1742 1882	1882 1925	C W A S H	Standing

Site Name	Area	Dates in Use First	Dates in Use Last	Features	Condition
New York					
(Richard Allen, Jack Chard, Theodore Kury)					
Clinton County					
Etna	Peru	1822		C W	Part of stack
Ketchum	Peru	1826		C W	Part of stack
Columbia County					
Beckley	Chatham	1873	1915?	C W	Standing
Copake	Copake Falls	1846	1901	C W	Standing: exterior stone removed
Dutchess County					
Clove Spring	Clove Valley	1873	1896	A S	Standing, but in danger of collapse
Sharparoon	Dover	1881	1883	A S	Standing: good condition
Essex County					
Colburn	Morian	1848		C S	Stack partly collapsed
Crown Point	Ironville	1845	1871	C S	Part of stack
Fletcher	Mineville	1865	1875	C S	Part of stack
McIntyre	Tahawas	1854	1857	C W	Stack in very good condition; boilers on top; most of blowing equipment survives
Franklin County					
Duane		1838	1849	C W	Base and part of stack
Lewis County					
Alpina		1848	1881	C W	Standing
Sterlingbush	Lewisburgh	1833	1881	C W	Standing
Orange County					
Greenwood	Arden	1811	1871	C W	Stack standing; poor condition
		1854	1885	A S	Standing: good condition, with charging bridge
Noble	Bellvale	1833	1837	C W	Stack in poor condition
Queensboro	Fort Montgomery	1780?	1800?	C W	Standing; some consolidation of masonry

Site Name	Area	Dates in Use		Features	Condition
		First	Last		
Southfields		1804 (rebuilt 1868: anthracite)	1887	C W – A S	Standing, deteriorating
Sterling	Sterling Forest	1751	1804	C W	Standing; restoration within monument
St Lawrence County					
Clifton	Clarksboro	1868	1869	C W	Base and part of stack
Coopers Falls	De Kalb	1853	1873	C W	Part of stack standing
Washington County					
Mt Hope	Fort Ann	C 1825-1836	C1858 or later	C W	Standing: good condition but lining missing
North Carolina					
Moratock	Danbury	1843	c1871		?Standing
Ohio					
(Emmett A Conway)					
Jackson County					
Buckeye	Milton	1851	1894	C S	Complete restoration; furnace and buildings
Cambria	Jefferson	1854	1878	C S	Stack in fair condition
Jefferson		1854	1916	C S	Stack in poor condition
Keystone	Bloomfield	1848	1885	C S	Stack in good condition: base cut through rock
Limestone	Madison	1855	1858	C S	Good condition
Lincoln	Milton	1854	1885	C S	Carved in solid rock: overgrown but good condition
Madison		1855	1902	C S	Stack in fair condition
Monroe	Monrow	1854	1882	C S	Partly collapsed
Lawrence County					
Buckhorn		1833		C S	Good condition
Etna	Pedro	1832		C S	Stack in fair condition
La Grange	Ironton	1836		C S	Fair
Oak Ridge	Arabia	1856	1859	C S	Good
Pioneer	Bloom	1856		C S	Stack poor
Vesuvius	Ellisonville	1832		C S	Restored

Site Name	**Area**	**Dates in Use**		**Features**	**Condition**
		First	**Last**		
Washington	Blackfork	1853		C S	Good
Mahoning County					
Hopewell (Eaton)	Struthers	1802	c1808-10	C W	Part of stack survives. Site excavated
Vinton County					
Big Sand	Hope	1854	c1880	C S	Standing: fair condition
Richland		1854	c1885	C S	Stack in poor condition
Vinton	Madison	1854 (rebuilt 1875)	1883	C – K	Base survives: front of stack collapsed; foundations of buildings; Belgian coke-ovens.
Oregon					
(Dariel Merrills)					
Oswego	Lake Oswego	1865	1885	C W	Restored stack
Pennsylvania	(Western sites largely derived from M B Sharp and W H Thomas **A Guide to the old stone blast furnaces in Western Pennsylvania** (Pittsburgh 1966, repr 1972) (sites marked (1966) are derived from this work; substantial additional comments by John R White, also from Helen Schenk).				
Armstrong County					
Bear Creek	Parker (Lawrenceburg)	1818	by 1850	C (experiments with coke and coal)	Lower part of stack (1966)
Biddle	Apollo	1825	1855		Lower part of stack: one arch (1966)
Brady's Bend		(1)1840 (2)1841 (3)1843 (4)1846		K H K K C H – S	Two of the four furnaces standing (1966)
Mahoning		1845 (rebuilt 1860)	1878	C – K	Stack in poor condition (1966)
McCrea	Mahoning Dam	1857			Stack collapsing (1966)
Beaver County					
Bassenheim	nr Zelienople	1814	1824		Part of stack standing (1966)
Bedford County					
Hopewell		1802 (rebuilt 1830/1)	1884		Part of stack visible (1966)

Site Name	Area	Dates in Use		Features	Condition
		First	Last		
Berks County					
Hopewell	Pottstown	(1)1770	1883	C W	Restored: complete
		(2)1853	1857	A S	Base restored
Joanna				A S H	Complete in good order; engine house
Blair County					
Allegheny	Altoona	1811	1818	C – K W	Restored stack (1966)
		1836	1884	C,K (1867) W	
Elizabeth	Altoona	1832		C H	Good condition (1966)
Etna	Yellow Springs	1807/9	1870	C H	Consolidated: arches blocked (1966)
Soapfat (Canoe)	Williamsburg	1839	1849	C	Part of circular stack surviving (1966)
Springfield	Royer (nr Williamsburg)	1815	1857		Stack standing but overgrown (1966)
Butler County					
Marion	Harrisville	1848/50	1862	C W	Part of stack, with one arch standing
Winfield	Saxonburg	1848	1864	C W – S K	Stack standing, base obscured by dumping (1966)
Cambria County					
Eliza		1846	1848	C H	Good condition: hot blast equipment visible on top (1966)
Centre County					
Centre	Waddle	1790	1809	C W	Standing
		1825	1858		
Eagle (Pleasant Furnace)	Milesburg	1848		C H	Restored (as cold blast)
Clarion County					
Blacks	Shippensville	1832	1859	W	Stack: ruined (1966)
Buchanan	Callensburg	1844	1858	C W	Fair condition (1966)
Eagle	Canoe Creek, Callensburg	1846	1858	C W	Good condition (1966)
Helen	Helen Furnace	1845	1857	S	Lining in fair to poor condition, outer stonework poor (1966)
Hemlock	Fryburg	1845	1865	W	Half (section) of stack standing (1966)
Mary Ann	Shippensville	1844	1851	C W	Part of stack barely remaining

		Dates in Use			
Site Name	**Area**	**First**	**Last**	**Features**	**Condition**
Richland	Alum Rock	1846		C W	Recognisable ruin (1966)
St Charles	New Bethlehem	1834	1865	C W – S H (1857)	Stack standing but overgrown (1966)
Clearfield County					
Karthaus		1817	1839		Stack in good condition (1966)
Fayette County					
Alliance	Perryopolis	1789	1802	C W	Parts of three walls standing, with 3-4 ft of lining; mill race visible
Center	Dunbar Creek, Uniontown	1815	pre-1859	C W	Furnace ruins, with wheelpit and building foundations (1966)
Coolspring	Uniontown	1820	1860	C W	Part of lining visible (1966)
Fayette	Normalville	1815	1840		Excellent condition (1966)
Mary Ann	Haydentown	1800 (rebuilt 1818)	1840		Ruins visible; tuyere present, forehearth caved in
Mount Vernon	Wooddale	c1805	1830	C W	Excellent condition
New Laurel	Dunbar	1812	1838	C W	One corner fallen, tuyere intact; wheel pit and mill race
Old Laurel	Dunbar	1797		C W	Rubble only; part of mill race
St John's	Indian Creek/ Normalville	1810	1828	C W	Part of stack standing (1966)
Wharton	Uniontown	1835	1873	C K H	Preserved and restored, including race
Forest County					
Forest	Tionesta	1853		W	Base surviving (1966)
Indiana County					
Baker	Armagh	1837 (rebuilt 1848		W	Foundations clear (1966)
Buena Vista	Armagh	1847	1856	C W	Three sides standing (1966)

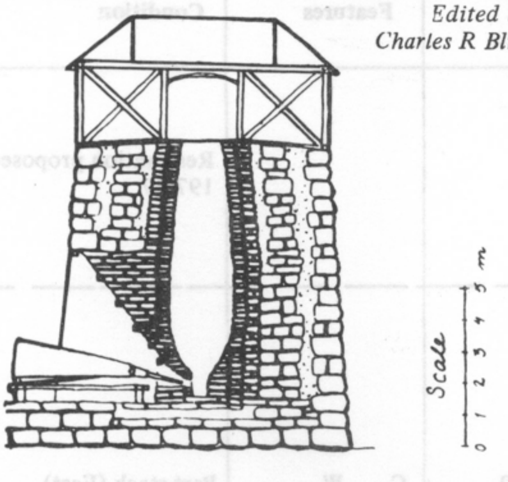
Site Name	Area	Dates in Use First	Dates in Use Last	Features	Condition
Lawrence County					
Lawrence	Energy	1846	1875	C	Built within rock into the ground – firebrick lined – good condition (1966) (for this technique of construction see Lincoln, Ohio)
Powers (Neshannock)	Harlansburg	1850	c1862		Small portion of internal wall surviving, also race, dam and wheelhouse foundation
Wilroy	Rose Point	1854	before 1877	C W	Well preserved
Lebabon County					
Cornwall	Fredericksburg	1742 1857	1856 1883	C W	Survives complete
Lehigh County					
Lock Ridge	Alburtis	(1)1868 (2)1869	1921	A	Restored
Mercer County					
Clay	Charleston	1845		H A	Remains of base
Springfield	Leesburg	1837	1862	C W	Foundation outline visible; wheelpit, retaining walls, axle notch
Somerset County					
Wellersburg	Wellersburg	1856	1866	C-K W H	Inner lining remaining (1966)
Venango County					
Bullion	Kennerdell	1840		C W	One side collapsed, part intact; wheelpit remains
Castle Rock (Sandy)	Polk	1836	1860	C W	Cross section with half furnace gone. Shows inner and outer walls well
Horse Creek (Clay)	Oil City	1832	1856	C W	Lower part of stack survives; in good condition (1966)
Jackson	Van	1833	1856	C W	Good condition (1966)
Porterfield (Mill Creek)	Emlenton	1837/8	1851/2	C W	Outside partially collapsing; lining good; casting floor and casting shed foundations intact

Site Name	Area	Dates in Use		Features	Condition
		First	Last		
President	Seneca	1847/57		C W	Deteriorating (1966)
Raymilton	Polk	1843/4		H C	Deteriorating, one arch visible; half original height; complex stone-lined race in excellent condition
Reno	Polk	1844	1848		Excellent condition
Rockland	Freedom	1832		C W	Excellent condition
Slab	Egypt Corners	1832	1855	C W	One side of outer stonework collapsed; unique construction of vertical unshaped slabs
Stapley (Shippen)	Mariasville	1835		C W – S	Inner stack standing; most outer stone removed; wheelpit
Union	Cooperstown	1844	1854	C W	Circular stack in poor condition (1966)
Valley	Wyattville	1848	pre-1859	C W	Circular stack with four openings; base only survives; race and dam
Van Buren	Franklin	1832	after 1854	C W	Fair shape, but with outer stonework collapsing
Victory	Franklin	1843	1850	C W	Excellent condition
Webster		1839		C W	Good condition; square base, octagonal upper stack (1966)
Westmoreland County					
Baldwin	New Florence	1810			Fair condition (1966)
California	Laughlinton	1850		C W – S	Restored with new hearth and lining (1966)
Fountain	Jones Mill	1812			Deteriorating (1966)
Hanna (Unity)	St Clair	by 1810		W B	Base surviving, with wheelpit (1966)
Luarel Hill	New Florence	1845/6	1855 or 1860	C W H	Good condition; four arches; deep wheelpit and tailrace culvert (1966)
Ross	New Florence	1815	1850	C W	Good condition; inner lining restored (1966)
Valley	Ligonier	1850		K H S	Good condition: four arches (1966)
Washington	Ligonier	1809 rebuilt 1848	1826 after 1854	C H	Outer stonework

Site Name	Area	Dates in Use		Features	Condition
		First	Last		
Tennessee					
Bluff Furnace	Chattanooga				Restoration proposed 1974-7
Cumberland Gap					
Vermont					
(Victor Rolando)					
Bennington County					
East Bennington		c1832 1822	c1840 1853	C W C W H	Part-stack (East) Part-stack (West)
East Dorset	Dorset	c1846	by 1854	C W	Stack standing
North Dorset	Dorset	c1840	c1850	C W	Part-stack
Orleans County					
Troy		1837	1846	C W	Part-stack
Rutland County					
Forestdale		1823	1854	C W H	Stack standing
Pittsford		c1865	c1880	C W H	Stack standing
Tinmouth		c1815	by 1850s	C W	Part stack
Virginia					
(James Goldsmith, Robert Vogel)					
Page County					
Catharine Furnace	Shenandoah	1836	1888	C	(Restoration proposed)
Hancock County					
Peter Tarr Furnace		1794			Restored
Rockbridge County					
Glenwood Furnace					
Elizabeth Furnace					
Fredericksville Furnace		c1728	c1736		Part stack
West Virginia					
(James Goldsmith)					
Monongalia County					
Davis Furnace					Stack collapsed
Henry Clay Furnace					

Early Blast Furnace News

Edited by
Charles R Blick



Mathrafal Forge – and Furnace?

New member P W King is researching the development of iron production – generally in the Midlands – from the introduction of the blast furnace to the coke smelting of iron in the late 18th century. As a solicitor, with a knowledge of the technicalities of land law, he claims to have arrived at different conclusions to some of those he has seen published, as a result of his researches in the Foley Collection in the Hereford Records Office. He has found a document of 1683 referring to **Madarfall** furnace – as if in use – and believes this to be **Mathrafal** indicating that there was a furnace on this site – as well as the forge, whose output is recorded in the **Lists** of 1717, 1736 and 1750.

Mathrafal is linked with Dolobran, in former Montgomeryshire, 25 miles west of Shrewsbury.

Dud Dudley's Blast Furnaces, Worcestershire (Himley – Dudley)

In 1967, in Volume 1 Part 1 of the Journal of West Midlands Regional Studies, there appeared an article entitled 'Dud Dudley – A New Appraisal' by G R Morton and M D G Wanklyn. Inter alia, the locations of Dudley's three blast furnaces were discussed. His first one at Cradley was the subject of personal reminiscences by Mr Evers Swindell, in 1907, when he said his father had 'pulled down what remained of Dud Dudley's blast furnace at Cradley Iron Works' in the 1830s. The site was known to Mr Swindells, then, but has since disappeared, destroyed or built over by mining operations.

A similar fate has befallen the site of the third of his furnaces at Hasco (now Askew) Bridge – destroyed by mining operations but the furnace pool can still be discerned on the left of the Himley – Dudley road. Morton and Wanklyn thought that the site of the second furnace at Himley was at the bottom of one of the eighteenth century lakes in the grounds of Himley Hall.

Dr Wanklyn has now written to say that this lake was drained during the summer of 1983 and there was nothing there. He can only assume that it was destroyed at the time Himley Park was landscaped, as the lease of 1625 established that it lay close to Himley Hall, that is, closer than the supposed site under the lake in the grounds.

We are grateful to Dr Wanklyn for this information.

Gunn's Mill Blast Furnace, Flaxley, Glos
MR SO 675159 (1628-9 rebuilt 1683 to C1732)

Ownership of this charismatic furnace has recently changed and the opportunity arises for restoration and conservation, Ian Standing reports. The Local Planning Department will consider grant aid and the DoE is considering scheduling.

Dovey Blast Furnace, Eglwysfach, Dyfi, Dyfed
MR SN685952 (1755 to post 1796)

An interim report has been received from the Inspector of Ancient Monuments, Dr Sian E Rees, covering 1983 excavations. These concentrated on the cast house area and seem to indicate a 'split-casting' facility – a pig casting bed in the northern part and a casting floor in the southern (cf **Bonawe, Glenkinglass, Moira).**

Within the stack the hearthstones, with adherent slag, iron and charcoal were lifted. A trial trench was cut across the tailrace from the original water wheel.

Consolidation of the roof, waterproofing of the top of the stack and making good the casting arch are nearly complete. The later, sawmill, wheel leat and dam are all repaired and serviceable – and the wheel turns under water power though there is no machinery to drive.

Moira Blast Furnace, Leicestershire
MR SK 314153 (C 1804 to C 1840)

Report No 1 January 1984, and a follow-up report of May 1984 have been received from David Cranstone, senior archaeologist of the North Western Leicestershire District Council. Much of interest has arisen, is arising and the final report – in due course – will be of great value.

The samples of burden and cindery material, taken from the stack in July/August 1982, were analysed by courtesy of the Managing Director, Brymbo Steelworks Ltd, to whom we owe our sincere gratitude.

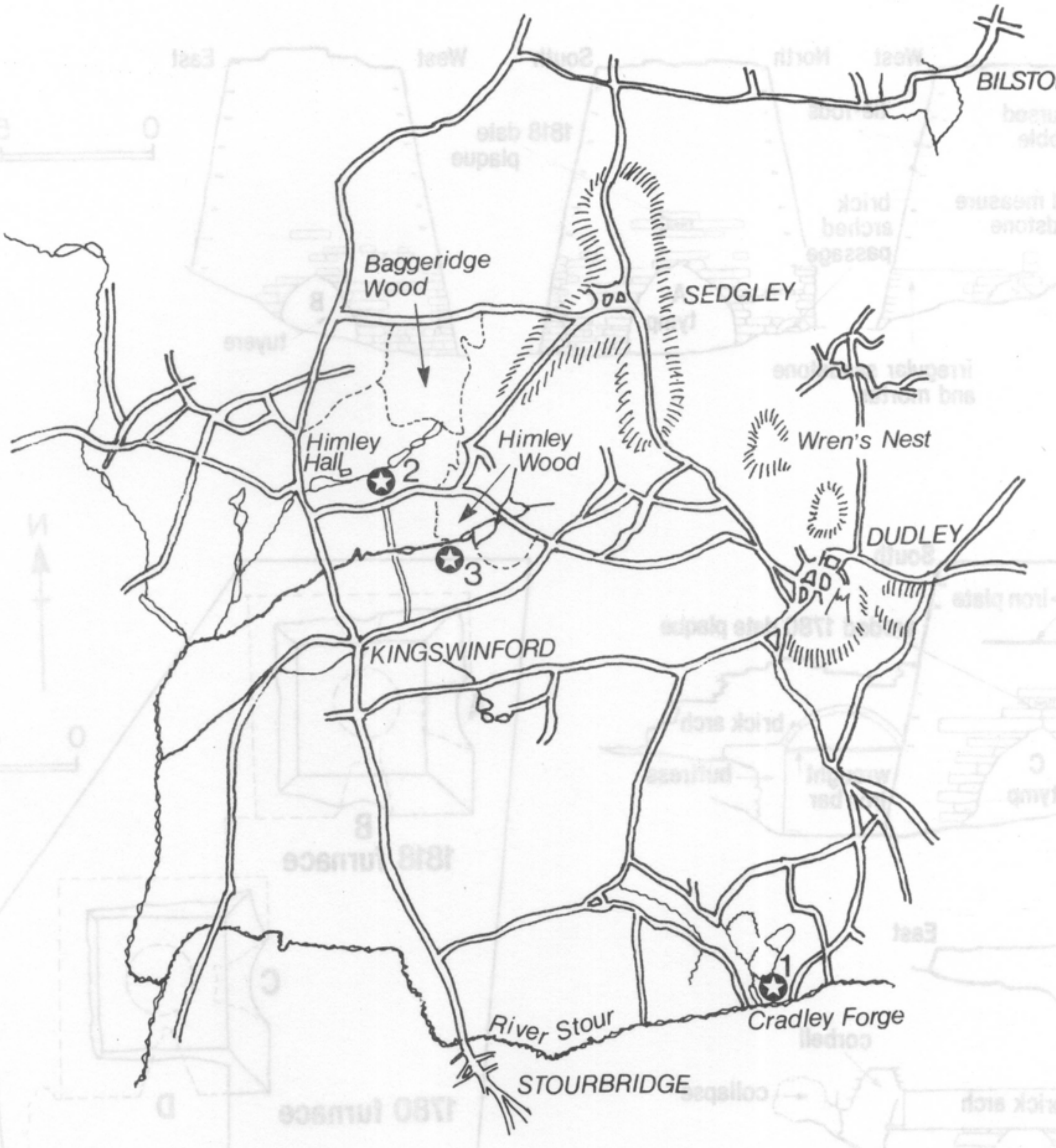
Professor Tylecote has examined these results, which covered material from the top of the bosh down to the bottom of the hearth. He reports that the high iron contents indicate some iron must have been in the metallic state and that there was a lot of unreduced ore, so that slag formation had been poor. The slag was a potential calcium silicate one with high sulphur, clearly signifying a coke/coal fuel. The samples were very heterogeneous and any further work must start with mineralogical phase analysis.

On the ground, the engine house site was excavated, the area around the blowing arches and the bridge house junction were cleared and the cast house area stripped. This casting area appears to indicate a 'split-casting' facility. (cf **Bonawe, Glenkinglass, Dovey).** The bridge house appears to consist of transverse tunnels to which the external walls are not wholly tied.

Between the engine house and the furnace lay a rectangular pit which might be a water regulator.

The two blowing arches open into a sunken passage extending around the west, south (bridgehouse) and east sides of the stack. Beneath the floor levels of the arches are brick lined pits connected to each other, the collapsed wooden covers of which have confused the stratigraphy. It is suggested that the blast main was connected through these, and the standing water therein would cool the air blast.

The throat and chimney were also examined: the northern half – opposite the charging hole – was well preserved and heavily fused. This information by courtesy of Post Medieval Archaeology.



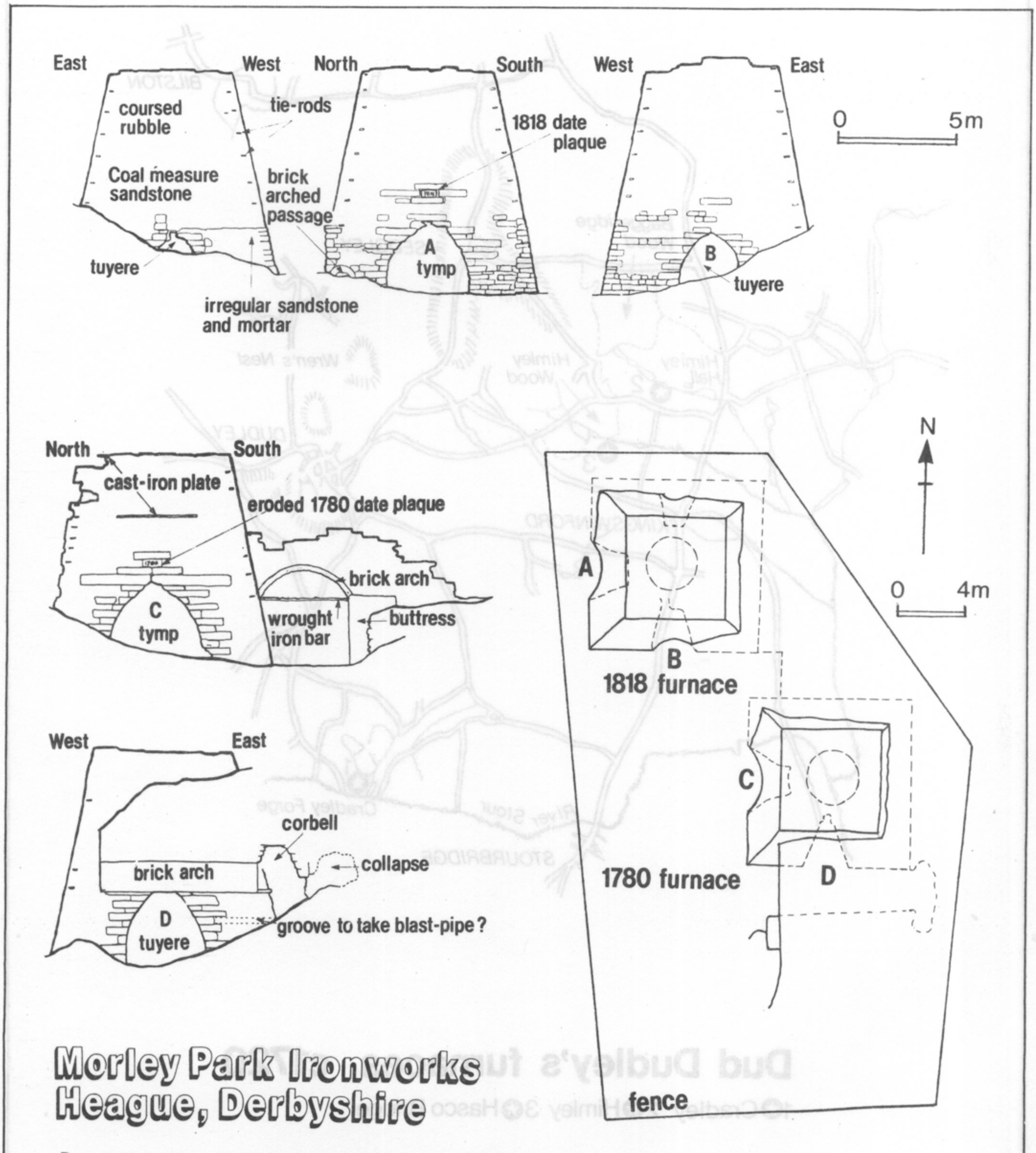
Dud Dudley's furnaces c1720

1✪Cradley 2✪Himley 3✪Hasco Bridge

Morley Park Blast Furnaces, Heague, Derbyshire
MR SK 380492 (1780 and 1818 to 1874/1875)

Keith Reedman reports that these two furnaces are now in the ownership of the Derbyshire Historical Buildings Trust and the work on restoration and conservation can commence as long as the promised grant is forthcoming. Derek Latham has been appointed architect and the work could be completed this year.

John Pickin, of Derby Industrial Museum, reports that the Museum has carried out a survey of these two furnaces, and has sent us copies, reproduced (reduced) herewith. We are very grateful for these.



Drawing by courtesy of John Pickin, Derby Industrial Museum

Dol-y-Clochydd Blast Furnace, Llanfachreth, Merioneth
MR SH 734222 (1597 to 1604)

Peter Crew, of the Snowdonia National Park Centre, will be excavating the site this year.

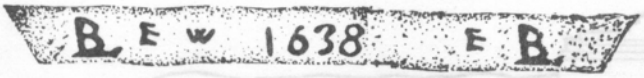
Bersham Blast Furnace, near Wrexham, Clwyd.
MR SJ 308493 (c 1750 to 1788)

Little is known of the one, possibly two furnaces on this site of John Wilkinson's famous works. Peter Crew will be investigating and we look forward to his report on this 'terre-inconnue'.

Coalbrookdale, The Old Furnace, Ironbridge, Shropshire
MR SJ 667048 (1638 rebuilt 1708/9 enlarged 1777 to c 1818)

In 'Historical Metallurgy' Vol 17/1 1983 the opening of the new Cover for the Old Furnace by HRH The Duke of Gloucester was reported. During the necessary excavations for this, an archaeological examination was made by J P Malam, Archaeological Supervisor, Institute of Industrial Archaeology. A full set of measured drawings of the structure was made: the site of the water wheel, c 2.25m radius, operating the bellows, was established from marks on the stonework and most importantly the discovery of a second blowing arch – on the north side – was made.

Contemporarily, Professor K J Holtgen, of the University of Erlangen, Nurnberg, put forward a possible explanation of the inscription on the oldest of the beams over the tapping arch.



He suggests the B with the wavy line is a 'rebus'. It indicates a 'B' and a brook. The crown is a rebus of Basil, meaning a king. The E stands for Ethelreda, daughter of Sir Edmund Brudenell, of Deene, Northumberland, whom Sir Basil married in 1605.

The inscription therefore reads:

'Brooke, Ethelreda (and) Basil 1638 Ethelreda (and)Basil Brooke'.

We are grateful to Ironbridge Quarterly 1982-3 for this information.

Nibthwaite Blast Furnace, Cumbria
MR SD 293898 (1735 to 1755)

The owner of this furnace recently applied for scheduled monument consent for the conversion of the buildings at Nibthwaite furnace into a dwelling. We were consulted, as well as the Cumberland and Westmorland Archaeological Society's Industrial Archaeology Committee. We found the conversion was to be most sympathetic, the base of the furnace not being disturbed and future access being allowed thereto. We accordingly registered no objection to the proposed conversion.

Newlands Blast Furnace, Cumbria
MR SD 299798 (1747 to 1891)

The owner of this furnace and buildings recently approached the Do E for advice on what work would be required to preserve and conserve this well-known unit.

The Do E carried out a full survey last year and costed the work necessary at about £38,000. It was thought likely that the full programme could be beyond the owner's resources but it was for him to decide how much work was to be done within available finance.

The Society has made a contribution – albeit small– towards the repair and restoration work, and this has been acknowledged with thanks.

Duddon Blast Furnace, Cumbria
MR SD 197883 (1736 to 1867)

David Cranstone directed a third season of excavations for the Lake District Special Planning Board to complete the programme initiated by Peter Brown.

The wheelpit and part of the adjacent tailrace were fully excavated.

It was found that the final wheelpit overlay an earlier, deeper and narrower wheelpit.

The interior of the stack was excavated to the original surface on which the hearth had been constructed, some 0.5m being removed. No traces of the hearth remained in situ.

A small area in the charcoal barn was investigated to locate any floor surfaces. The working floor was found just under the modern top soil, and preserved evidence of the internal arrangements of the barn.

This information by courtesy of Post Medieval Archaeology.

Blaenavon Ironworks, Pontypool, Gwent
MR SO 248093 (1790 to c 1900)

Restoration work continues on this most important C18 and C19 site – which was visited by members at the Annual Conference in the Sidney Gilchrist Thomas Centenary Year 1978 – which is in the care of the Welsh Office.

Stanley Coates and Colin Davies recently visited the site with their Inspector of Ancient Monuments, Mr Jeremy Knight, and noted progress of works.

Darkhill Blast Furnace, Forest of Dean
MR 590087 (1818 – 1847)

The condition of the remains of this furnace, and works, associated with David Mushet and his son Robert Forrester, is causing some concern.

Spiers Bank Blast Furnace, Hartoft End, Rosedale, North Yorkshire
MR SE753931

Dr Magnusson confirms the presence of an early blast furnace on this site.

The Charcoal-Fired Blast Furnaces of Scotland – A Review

We are privileged to have had a view of this unfinished paper by John H Lewis. It covers the work done by him, Chris Tabraham and John Hume for the Scottish Development Department over the last four years.

The excavations and remains at the following sites are reported on in detail:-

Bonawe	NGR	NN 009318
Craleckan	NGR	NN 027001
Glenkinglass	NGR	NN 082371
Red Smiddy	NGR	NG 861798 (c 1612 - 1668)

The following iron working sites were visited:-

Culnakyle	NGR	NH 996217 – blast furnace not located
Fasagh	NGR	NH 011654 – probably a bloomery + two forges: not excavated
Invergarry	NGR	NH 313010 – blast furnace recognisable, not excavated
Letterewe	NGR	NG 958705 – probably high bloomery, later conversion to a blast furnace – not excavated
Tarrioch	NGR	NS 642269 – site described

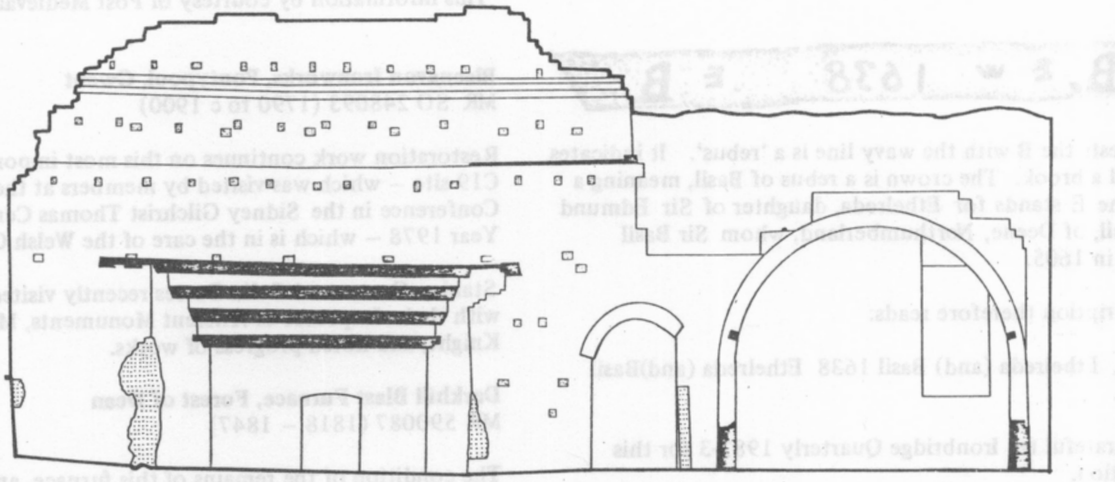
This is an extremely interesting and valuable report.

'Split' casting areas were exposed at **Bonawe** and **Glenkinglass** – cf **Dovey** and **Moira**. One half appeared to be a normal sand casting bed – for pigs of iron, while the other half was a casting floor on which moulds were placed and filled with liquid iron to make finished castings.

The excavations at **Red Smiddy** were reported in Early Blast Furnace News Vol 16/2, 1982.

News Item

The site on which stand the remains of six blast furnaces of Cyfarthfa Innworks (map reference S0 038070) has been presented to the Merthyr Heritage Trust for preservation.



The Old Furnace Coalbrookdale
One of the new survey drawings

Drawing by courtesy of Institute of Industrial Archaeology

Notes and News

Recent Conferences:

Il Primo Ferro Nel Mediterraneo was the title of an international symposium, organised by the *Istituto di Studi Etroschi ed Italici, Firenze* (Dr G Maetzke) with the co-operation of the *Comité pour la sidéd rurgie ancienne de l'UISPP.* Special thanks are due to *Dr G Sperl* (Inst f Festkörperphysik, Leoben) a member of the Comité, who was responsible for the organization at Firenze, Volterra, and finally at San Vincenzo, near Populonia, the venue for the sessions. This was the sixth archaeo-metallurgical symposium with which the Comite was involved in an initiative and advisory role.

Some 30 scholars from 14 countries took part (Italy, Austria, Great Britain, United States, Czechoslovakia, Poland, Hungary, Greece, Denmark, Federal Germany and Sweden). The papers were divided into several groups: Group 1. The first appearance of iron in Italy:- (a) *F Delpino:* Prime testimonianze dell 'uso del ferro in Italia; (b) *F Lo Schiavo:* Il ferro in Sardegna; (c) *G Bartolini:* Insediamenti della tarda eta del bronzo nei pressi di Populonia. Group 2. The metallurgy of iron at Populonia and on the island of Elba: (a) *O Voss:* The iron production of Populonia; (b) *G Sperl:* The structure of slags from Populonia and Elba. Group 3. The problem of copper metallurgy in relation to iron and steel metallurgy: (a) *V C Piggot:* Early iron metallurgy in the Eastern Mediterranean; (b) *P T Craddock:* Iron in Etruscan copper: an indication of the smelting process; (c) *J -R Maréchal:* Passage de la métallurgie du cuivre à celle du fer (presented by C Calzolani); (d) *R Pleiner:* On the quality of iron during the Final Bronze Age; (e) *R Maddin:* Iron technology in Cyprus: ca 1200-1000 BC; (e) *R Maddin:* Research on iron at the Etruscan site of Murlo (Tuscany). Group 4. Metallurgy in the light of linguistic and written sources from Antiquity and the Middle Ages: (a) *G Sperl:* The name of iron in the Mediterranean; (b) *J Piaskowski:* Metallurgy in Pliny's 'Historia naturalis'; (c) *B G Scott:* Iron smelting and working in the early Irish Law Tracts. Group 5. Discoveries of iron ore mines, bloomeries and investigations of iron objects in other parts of Europe or the Old World; (a) *K Bielenin* and *E Nosek:* The ancient iron ore mine from the Roman period at Rudki, Poland; (b) *I Serning:* The reducibility of iron ores found on protohistoric sites (presented by P Kresten); (c) *J Gömöri:* The Szakony bloomery workshops (10-11th centuries AD); (d) *J Piaskowski :* The earliest iron in the world; (e) *R Maddin:* An axe of the 17th-16th century BC from Jordan: (f) *R Maddin:* Metallographic investigation on Hittite iron related to the ' Iron letter'; (g) *T F Tylecote:* Metallography of cutting tools. Group 6. Supplementary topics: (a) Experimental production of Etruscan bronze fibulae by *E Formigli;* (b) Gypsum burning by *H Killius.* In addition to the lectures there was a meeting of the 'slag group', concerned with the chemical and mineralogical investigation of bloomery slags (present G Sperl, P Kresten, R Pleiner, B G Scott, R Clough); work in progress and the future programme were discussed.

An integral part of the symposium was the programme of excursions, which took participants to sites related to the original sources of the problems discussed during the sessions; 1. to Populonia, with its huge Etruscan bloomery slag deposits in Baratti Bay; to Elba (mines and slags at Capo Pero, Rio Marina, and Prochio); 3. to Fucinaia and Massa Maritima (13th century copper smelting, iron-bearing copper slags); 4. Valpiane and Follonica (19th century) charcoal blast furnaces).

The sessions were graced with the presence of civic dignitaries from San Vincenzo and Piombino, including representatives of the iron and steel works at Piombino.

R Pleiner, Prague

Approaches to Ancient and Medieval Tin

A one-day conference was hosted by the Archaeology Section at Exeter University on March 3rd 1984. This was introduced by Professor Malcolm Todd. The main speakers were Dr R C Scrivenor of the Institute of Geological Sciences who described the tin deposits in the South-west; Neil Beagrie, who talked about tin ingots and cassiterite from western Europe; Dr T A P Greeves who gave a paper on tin dressing and blowing – the development of mills in the south-west from the 15th to the 20th century; and Sandy Gerrard who described his work on the Colliford tin works on Bodmin Moor. R F Tylecote gave a paper on the tin plating of bronzes, iron and other materials.

There was a lively discussion and it was clear that such conferences should be held more often to discuss the work proposed and in progress in the south-west.

There are no plans to publish the conference proceedings but it is hoped that most of the papers, if not all, will be published in this Journal in due course.

RFT

Scientific Activity:

Physical and Chemical Investigations into Slags from the Mazowsze Bloomery Sites in Poland. The Laboratories of the Institute for the Study of Material Culture, Warsaw, have recently been studying under the leadership of Z Hensel, bloomery slags originating from extensive Late La Tene and Romano-Barbarian period smelting sites in the Mazowsze region, west of Warsaw. Production was based upon rich phosphorus and manganese bog iron ores (up to 3.78% P_20_5, 13.5% Mn0, but now only up to 30% Fe_20_3). The bloomeries were based on non-tapping slag-pit furnaces producing heavy slag blocks. Three of the blocks, from the site at Milanowek, together with some comparative samples from Africa and the Holy Cross Mountain area, were submitted to chemical and X-ray diffraction analyses, optical mineralogy, DTA, high-temperature microscopy etc. The slags, which were very rich in phosphorus (up to 7.4% P_20_5, 1.7% Mn0, 3.9% Ca0, 1.5% $Si0_2$, 1.4% Al_20_3, 46.1% Fe0) were easy to melt, at about 1100°C. The mineralogical composition comprised some wustite, fayalite or a manganiferous olivine product. It is believed that there was deliberate addition of lime fluxes (lime kilns in the vicinity) in order to dephosphorize the smelted iron. The yield of the Milanówek furnaces is estimated to have been 20% in relation to the ore weight, and 36.5% to the slag weight.

After Z Hensel, Warszawa

Research Centres:

Research Programme H 27 on Mines and Metallurgy in Eastern France from Antiquity until Modern Times was inaugurated at Dijon in 1982. Its goals and activity are reflected in the first Bulletin (1983-1), edited by Prof Michel Mangin of the University of Besancon (Institut d'archaeologie, Faculté des Lettres). Many scholars from different institutions are involved (J -P -Jacob, B Bohly, M Mangin, M Rilliot, I Grandemange, J Dupraz, P Benoit, B Ancel and others); specific regions have been designated:- Burgundy – Franche Comté, Alsace – Vosges, and Alpes du Nord. In these regions, survey and recording work is carried out on mines and metallurgical remains by scientific teams headed by the scholars listed above. The bulletin contains details of the initial survey and experimental projects and reports on archaeo metallurgical symposia and conferences and consultancy work abroad.

After M Mangin, Besancon

Another Foundry in Exeter

In our issue for 1983, Part 1, we mentioned the excavation of the Pennington bell foundry in the St Paul district of Exeter, Recently, Chris Henderson has excavated another foundry in Exeter, the Birdall Foundry for the making of skillets and cauldrons, dated to about 1560-70. This site has produced a deep ash-pit reached by steps down, a firebox, but again no hearth. The moulds had been made using the clay pattern technique which replaced the wax investment. The cores had been hollowed out before casting to decrease their mass and enable them to be dried more efficiently as well as to reduce their resistance to shrinkage on solidification. It seems that the moulds for the legs and handles had been made separately and prefired and then built into the main mould like a core. Separate from the casting pit and furnace was another room with a moulding bench and drying hearth.

Analyses are being made of the small amount of bronze found. It is likely that this will turn out to be a plain tin-bronze rather than a bell-metal which would have been too high in tin for cauldrons.

The site has been excavated by the Archaeological Field Unit of Exeter City Council Museums Service which kindly provided the information on which this note is based.

RFT

Excavation of Lead Mill in Co Durham

Killhope (NY/826429). In 1982 P J Brown for Durham County Council directed a first season of excavations at the Park Level Mill. The standing remains date from 1878, when a new crushing mill began work at the head of the lead mine. The large overshot wheel had powered a crushing machine next to the jigger house. The interior of the jigger house was completely excavated, revealing the drains, and bases for the jigging machines, set in pairs. Evidence for seven jiggers survived, although two additional machines may have pre-dated the second crushing machine at the W end of the building. The standing fabric was also examined for evidence of the working components. Further excavation work is planned for the buddle house, and the areas of terracing of the complex. An archive report of work to date has been filed with the County Planning Department.

David Cranstone continued the programme of excavations in 1983. Work concentrated on the bouse teams and the west end of the washing floor. The row of ten bouse teams was shown to have been constructed in two stages, the two easternmost being additions. Only the upper levels of the washing floor were investigated; these showed rubble-covered timber platforms along the north and south sides, while (at the levels reached) the central strip was vacant except for a square stone foundation (perhaps for a grating), and an adjacent timber structure. It is hoped that further excavation in 1984 will elucidate the functions of the structures observed.

During the excavation, erosion caused by flooding of the Killhope Burn revealed a drystone revetment wall to the ore processing area, protected by timber breakwaters on its outer face. This wall had later been completely buried by the mine spoil heap.

RFT

Book reviews

Les Ors Préhistoriques, *Christiane Eluère, Picard, 82 Rue Bonaparte, Paris 6e, 1982, 287 pages, price Ffr 250.*

Just as with other aspects of ancient metallurgy, prehistoric gold work has been the subject of a number of scientific studies in recent years. British technology in the Bronze Age was ably reviewed by Dr Joan Taylor in 1981 and now we have a rather similar comprehensive study by Mlle Eluère of the Musée des Antiquites Nationales at St Germain-en-Laye.

The objects described number over 400 from most regions of France and include jewellery of many types, vessels and small ingots and stocks of metal waiting to be worked, all dating from the period from the third millenium until the end of the eighth century BC, by which time the great activity in gold working had diminished throughout Europe.

A detailed description of the forms of the gold artifacts, fully illustrated, is followed by chapter outlining the role of gold in the economy and the culture of the Bronze Age and of the activities of the goldsmiths whether itinerant or based in smaller or larger settlements. Throughout the book an attempt has been made to establish connections between form and technique of working and between the latter and the quantity and the composition of the raw materials available to the goldsmith. The varying compositions of the gold alloys analysed are displayed in ternary diagrams giving the relative contents of silver, copper and tin with comments upon the geographical reasons for these variations.

There is an extremely extensive and valuable bibliography and of course an inventory of all the artifacts found in individual parts of France.

L B Hunt

Iron and Steel: No 2 in a Series of Technological Essays as part of the Open University's Arts: A Second Level Course, Technology and Change, 1750-1914. ISBN 0 335 112536; A4 format. Obtainable from the Open University Press, Milton Keynes.

The section on Iron and Steel forms 30 pages of the complete 88 page booklet. The other sections are – Technological Change in the Textile Industries and The Age of Steam Power which are not reviewed here. This essay has been prepared for the Course Team by **Colin Chant**. Twenty seven references are given, of which three:

Gale, W K V (1969), *Iron and Steel*, Longmans,

Hyde, C K (1977) *Technological change and the British Iron industry 1700-1870*, Princeton University Press,

McCloskey, D N (1973) *Economic maturity and entrepreneurial decline: British Iron and Steel 1870-1913*',
Harvard University Press,

are recommended for further reading.

The course is currently going out to registered students for the first time. If all goes well all the course material will be generally available early in 1985.

Supporting the text are associated audiovision sequences and television programmes.

The author acknowledges the assistance given by **Dr J K Almond**, of Teesside Polytechnic.

The Essay is in three parts:

1 The industrial revolution in iron,
2 The ascendancy of wrought iron,
3 The advent of bulk steel.

The introduction to Part 1 reads:

'Until near the end of our period, technological change in the processing of iron and steel . . . emanated largely from Britain; this essay therefore focuses largely on the effects of the main innovations on the British iron and steel industry as well as on details of the new techniques. Inevitably, some important aspects of iron and steel production have been passed over briefly or even entirely . . . some of these fall properly within the domain of other essays; some are covered more fully in the audio and television programmes (q.v.).

Two points should be emphasised at the outset. First, our knowledge in detail of the processes to be described is incomplete . . . Second, within the space allocated, it would be impracticable . . . to unfold the history of iron and steel production wholly in accordance with the terminology and scientific understanding of its participants'.

A description of the chemistry involved in the smelting of iron ores follows. The charcoal iron industry is then well described and this leads to the substitution of coke for charcoal in the smelting process. Abraham Darby's development is examined as are the reasons why it apparently took 50 years, from 1709, for the coke substitution process to spread noticeably and this, it is concluded, finally came about with the increasing cost of charcoal and the decreasing cost of coke.

John Wilkinson and the application of steam power for the airblast, in the 1770s, is then considered and confirmed as the reason for the spectacular enlargement and significant relocation of the industry as a whole. Better quality iron became available, more coal could be used and more efficient iron extraction from the ore became practical.

This is followed by the advent of the puddling and rolling processes, in the 1780s, it being noted that Henry Cort's work was in essence a synthesis of existing elements. Certain refinements to Cort's original process were introduced, steam power was applied to rolling mills and these, together with certain economic factors, caused a dramatic expansion in the output of wrought iron.

Finally, the first process for the production of molten steel – Benjamin Huntsman's crucible process – is described. It is concluded that the charcoal to coke transition, and steam-water power substitution, enabled the relocation of the industry, and its rapid expansion, to take place in 'new' areas like South Wales and the Black Country with declines in the Weald and Forest of Dean. In value terms, the iron industry became the third in the British economy after cotton and wool. The British Iron Industry was supplying the revolutions in machine technology – steam engines, textile machinery – and transportation.

Part 2 covers developments in the blast furnace and its process – and in the puddling process.

Changes in profile and construction of the furnace stack are noted, and the economics therefrom, but the greatest economics came from the introduction of heating to the air blast by James Neilson's patent of 1828.

Instead of cooling the blast as heretofore, it was found that hot air blast, even to the first low practical temperatures achieved, produced significant fuel savings. The spread of its use was not general however. It started in Scotland, spread to Staffordshire then South Yorkshire/Derbyshire and finally to South Wales and this, it is shown, is correlated to the carbon content of the coals of those areas: the highest being in South Wales where it was found possible to use anthracite as the fuel.

Joseph Hall is credited, principally, with improvements to the puddling process enabling grey pig iron to be used – without a refining furnace – so leading to much greater efficiencies and improved quality of wrought iron – to the 'pig boiling', or 'wet' puddling process.

These developments leds, over 1830 to 1870, to a symbiotic relationship with the railways, comparable with the older alliance with the steam engine. Railways demanded rails, wheels, engines and provided a cheap means of transport. The world wide railway boom undoubtedly benefited the British Iron Industry although the seeds of its decline were being sown. Other countries, with abundant but less conveniently located resources, could begin to take advantages of the new coal based technology.

At home, new iron industry locations were in the North East and North West and in value terms the industry overtook the cotton and wool industries, employing some 40% of the adult male labour force.

Water and gas supply systems, engineering and general construction work burgeoned.

Part 3 deals with the advent of bulk steel and its traumatic effect on the iron industry.

The pneumatic process is first considered, wherein air is blown through molten pig iron and the unwanted metalloids are removed. Conceived by William Kelly, in America, and Henry Bessemer in England, contemporaneously, but patented by Bessemer first, in 1856, the demand for cheap steel appeared about to be satisfied – but not so. Many problems had to be resolved and here Robert Forester Mushet and G F Goransson were principals: then steel – principally for railway rails – was available from hematite – non-phosphoric – ores.

In ten years, however, another process, fathered by Charles William Siemens was in contention as a result of two requirements – to make cast steel by immersing wrought iron in molten pig iron and to pursue fuel conservation and economics.

Fuel conservation started at the blast furnaces where 'waste' gases, from the top, were entrained to raise steam and to heat the air blast – via hot blast stoves which operated on the regenerative principle. This principle was the basis of Siemen's open hearth furnace.

All this is well described, it being observed that the Bessemer converter had its most successful years during the period of world wide railway construction – when cheap steel rails were required in great quantities: the Siemens furnace came into its own as engineers began to demand higher quality and more specialised steels.

Both processes were however unable to produce steel from phosphoric iron ores. The key to this problem was provided by Sidney Gilchrist Thomas who master minded the basic lining for the Bessemer converter, which then became the Thomas converter. This process unlocked the enormous reserves of phosphoric ores on the Continent, and so the domination of the British iron and steel industry started to wain.

In conclusion, the writer believes that this decline was not the fault of the economic decisions of the late nineteenth century entrepreneurs but in the technology. The decisions, he claims, were essentially rational but in the early years of the twentieth centuries it was becoming uneconomic to extract the low grade basic ores of Lincolnshire and Northamptonshire – the only bulk ores remaining in the UK, with the depletion of the Cleveland, North Yorkshire, ores.

This whole essay is well documented and illustrated and makes very interesting reading. It is capably written and if the other 13 are as well done – as numbers 1 and 3 also appear to be – the whole will provide a satisfactory and satisfying exercise. It is recommended.

C R Blick

Early Metallurgy in Cyprus, 4000-500 BC, *edited by J D Muhly, Robert Maddin and Vassos Karageorghis. Nicosia, 1982, 382 pages and 38 plates in A4 format. Available from the Pierides Foundation, PO Box 25, Larnaca, Cyprus. Price 48 dollars in UK; 56 dollars in USA (post free).*

At last we have the Acta of the International Archaeology Symposium held at Larnaca between the 1st and 6th June 1981. It has taken its time but to those who specialise in Cyprus was well worth waiting for.

As we have reported the conference proceedings in detail in our Journal for 1982 (Vol 16, Part 2, pp33-34) we do not need to discuss the papers of the individual authors again but merely say that nearly all of them are printed in this volume together with the discussion.

This symposium was sponsored by the Pierides Foundation in collaboration with the Department of Antiquities, Republic of Cyprus, and the Foundation, editors, and printers are to be congratulated in bringing this marvellous work to fruitition.

R F Tylecote

Brief biographies

Brief biographical details of many of the authors whose papers appear in this issue, are given on the final page of the article concerned. Occasionally however, publication in this form would take the text onto a new page. Below are details of three of our authors which should be read in conjunction with their papers. **Dr E M Trent** and **E F Smart** are the authors of the article on Machining wrought iron (page 82) whilst **Professor Fred Adams** is a joint author of the paper on Himalayan statues (page 105).

E M Trent studied metallurgy at Sheffield University where he obtained his B Met and PhD. He was later awarded the D Met. He became Research Metallurgist for Wickman-Wimet in 1942 where he stayed until 1968 working on cemented carbides. He became lecturer in 1968 in Industrial Metallurgy in the University of Birmingham and from 1979, Hon Research Fellow. He is the author of *Metal Cutting,* Butterworths 1977 (84).

E F Smart is Senior Technician in the Dept of Metallurgy and Materials, University of Birmingham and the practical partner in all aspects of work on machining and the author of more than 15 papers.

Fred C Adams is professor of Chemistry at the University of Antwerp, Belgium with a teaching assignment on analytical chemistry and radiochemistry. He obtained a Doctorate in Chemistry at the University of Ghent, Belgium in 1963 and was involved until 1972 in the development of nuclear analytical methods and their applications at the University of Ghent. Since October 1972 upon the institution of the Graduate School (UIA) of the University of Antwerp he has been involved with the development of the Centre for Trace and Microscopical Characterisation of Materials relying on spectrometrical and mass spectrometrical techniques. He is the author of 3 monographs and about 250 scientific publications. Since October 1983 he has been the rector of the UIA campus of the University of Antwerp.

Abstracts

GENERAL

K Bielenin: Prospection of Archaeological Monuments using Modern Technical and Scientific Methods. *Bodendenkmalpflege Berlin, 1983, 79-97 (In German).*

Application of aerial reconnaissance and magnetometric prospection in the Holy Cross Mountain bloomery research programme. No less than 26 bloomery sites were discovered in the area of a single community (Lomno) in this way. Positive results were also obtained for sites with slag pit furnaces in Germany (Zells-Bahren, 12 sites; Wiederau, Langennaudorf Uebiggen).

G F Carter, E F Caley, J H Carlson, G W Carriveau, K Rengan and C Segebade: Comparison of Analyses of Eight Roman Orichalcum Coin Fragments by Seven Methods. *Archaeometry, 1983,* **25** *(2), 214-226,*

Eight orichalcum (brass) Roman coins were analysed for the elements Fe, Ni, Cu, Zn, Ag, Sn, Sb and Pb by seven methods; wet chemistry, wavelength dispersive X-ray fluorescence, energy dispersive X-ray fluorescence using a radio-active source of excitation and using an X-ray tube for excitation, neutron activation, atomic absorption and photon activation analysis. Although some methods gave a few results relatively far from the mean, most of the results were fairly close to the mean (consensus) values. However, most determinations were farther from the mean than expected from the precision of the individual methods. Undoubtedly much of this variation is due to the inhomogeneities in the coins, and various methods respond in different ways to inhomogeneities. Only a few random determinations were far from the mean indicating good reliability for the various methods.

Author

P Kersten and I Serning (Mrs): The Calculation of Normative Constituents from the Chemical Analyses of Ancient Slags. *Ternkontorets Berghistoriska Utskott H 25 (Archaeometallurgical Institute, University of Stockholm, 1983, Report 8. (In English).*

The proposal is made to consider chemical analyses of early iron smelting slags in relation to their qualified mineralogical composition, so that the chemical composition is revised by dividing the weight percentages of the oxides by the appropriate molecular weight. This norm may help to build up a more suitable classification of early slags. The main groups appear to be: 1, wüstite-normative slags. 2, olivine/fayalite/pyroxene-normative slags, which are evidence of improved smelting process. 3, quartz-normative glassy blast-furnace slags with minimal iron contents.

CPSA

J R Dennis: Niello: A Technical Study (6th Century Byzantine). *Washington DC, US Govt Printing Office, 1981, 15. (Available from NTIS, Springfield Va, order no PB81-249567).* *BAA*

S La Niece: Niello. An Historical and Technical Survey. *Ant Journal, 1983, 63 (2), 279-298.*

X-ray diffraction analysis of 180 objects from the 1st century AD to the present shows that Roman niello consists of a single sulfide usually copper or silver. Double sulfides become common from the 6th century on and lead was added as early as the 11th century in E Europe. *PTC*

R Newman, J R Dennis and E Farrell: A Technical Note on Neillo. *J American Inst for Conservation, 1982,* **21,** *80-85.*

Study of 12 neillos from Byzantine objects detected acanthite Ag_2S, elemental silver and jalpaite, mixed copper silver sulphide. Thus both single and double sulphides were in contemporary use. *PTC*

R C Mackenzie: The History of Thermal Analysis. *Thermochimica Acta. 1984,* **73** *(3), 249-367.*

A special issue of the journal devoted to this theme. This author has contributed two papers that survey the whole subject.

(After LBH in the Platinum Met Rev)

W A Oddy: Gold in Antiquity: Aspects of Gilding and Assaying. *Journal of the Royal Society of Arts, 1982,* **130,** *730-43.*

Gilding by foil was the first method, followed by gilding with leaf and this by fire (mercury) gilding which became common in Roman Europe in the third century AD, although used in China 500 years earlier. Analyses of 30 items show that early Roman cast sculpture had high lead contents but that the later gilt castings had necessarily low lead. Fire assaying dates back to the Middle Bronze Age and the touchstone to the 6th century BC. The latter depending on the colour of the streak of an alloy rubbed on a stone gives instantaneous results of surprising accuracy.

D A Scott: A Note on the Dissolution of Ancient Gold Alloys. *Archaeometry, 1983,* **25** *(2) 227-9.*

Methods for dissolving ancient gold alloy samples for analysis are discussed with reference to the difficulties encountered in keeping gold, silver and copper in solution. Possible techniques designed to overcome the problem are suggested and include ultrasonic vibration, the separate determination of silver and the method of salt additions to the aqua regia solution. *Author*

BRITAIN

P M Barford: Possible Metalworking Debris from Skeleton Green (?Tuyère). Hertfordshire Archaeol, 8, 1982, 200. *BAA*

P T Craddock: The Aston (Herts) Mirror: A further Note (Metal Composition). *Antiq J, 1983,* **63,** *130.* *BAA*

L N W Flanagan: The Irish Earlier Bronze Age Industry in Perspective (Axe Numbers, Copper Production). *J Roy Soc Antiq Ir, 1982,* **112,** *93-100.* *BAA*

A H Graham: Excavations in the Nave of the Parish Church of Sydling St Nicholas, Dorset (Medieval; bell-founding pit). *Proc Dorset Natur Hist Archaeol Soc, 1982,* **104,** *127-36.* *BAA*

J Gould: The Lichfield Canal and the Wychnar Ironworks. *Transactions of the South Staffordshire Archaeological and Historical Society, 1981-82,* **23,** *100-116.*

Wychnar is on the river Trent between Lichfield and Burton. A forge rolling and slitting mill was set up there by a local group, including Erasmus Darwin, in 1765 and worked for some sixty years. It operated by water power and had good access to the Trent and Mersey canal. Its history is detailed but little is left of the disturbed site beyond the mill pool and sluices. A schedule of the plant in 1825 is included. *PTC*

R Haslam: Iron by the Welsh Method – Cyfarthfa Ironworks. Merthyr Tydfil (Conservation). *Country Life, 6 October 1983,* **174,** *916-7.* *BAA*

H Howard: An Axe Core from East Kennet (Petrological Analysis of Clay Core from Armorican Socketed Axe). *Wiltshire Archaeol Natur Hist Mag, 1983,* **77,** *143-4.* *BAA*

J R Kenyon: A Cannon Shot Moved from Raglan Castle, *Gwent Arch Cambrensis 1982,* **131,** *142-43.*

Records the discovery of a mid 17th century shot made of chill cast iron. *PTC*

M B Mitchener and A M Pollard: Tin-Plated 16th Century Nuremberg Reckoning Counters from the River Thames (XRF Analysis of Coatings). *Numis Circ, 1983,* **91,** *152-3.* *BAA*

S W K Morgan: Development of the Zinc-Lead Blast Furnace as a Research Project. *Institution of Mining and Metallurgy, Transactions Section C, December 1983,* **92,** *192-200.*

Description of the development of the zinc-lead blast furnace at the Avonmouth plant of the Imperial Smelting Corporation. Although small scale work in 1943 had shown that liquid zinc could be condensed from exit gases from a shaft furnace by the use of molten lead as a shock chilling agent, intensive work did not begin until 1947 when a pilot furnace with a nominal productive capacity of 2t/day zinc was built. Further basic problems had to be solved and by 1960 a furnace that had a shaft area of 17.2 m with a nominal production capacity of 53000 t/year and 12000 t/year lead was erected at the Swansea Vale works. It was adopted as a prototype for the 13 other units that have been built and by 1980 these units had produced together more than 10 000 000 t zinc and 5 000 000 t lead.

Author (abridged)

R F Tylecote: A Survey of Iron and Steelmaking Sites in the Tyne-Wear Area of the United Kingdom. *Canadian Inst of Mining and Metallurgy, 1983,* **76,** *33-34.*

Particular emphasis is given to the introduction of the blast furnace, the early use of the coal in ironmaking, and the use of the steam engine, which made possible the integrated iron and steel works. Many site plans and sections through furnaces and kilns are reproduced. *APG*

C J Salter: The Relevance of Chemical Analysis to Provenance Studies of Celtic Ironworks in Britain. *Bul Inst of Arch, 1982,* **19,** *73-81.*

Chemical analysis of ironwork, coming especially from the Iron Age hillfort at Danebury, Hants, shows a tight clustering, suggesting a single source. Some SEM work on the inclusions suggest possible sources for the iron. *PTC*

C J Williams: The Lead Mines of the Alyn Valley. *Flintshire Hist Soc J, 1979-80,* **29,** *51-87.* *BAA*

EUROPE

H G Bachmann: Nineteenth Century Platinum Coins; An Early Use of Powder Metallurgy. *Platinum Met Rev, 1984,* **28** *(3), 126-131.*

Gives analyses of Pt from Russian placer deposits and photos of two nuggets, one 2cm across. One of the Urals nugget contains 10% Cr. *RFT*

T Balabanov: Iron and Copper Workshop at Pliska. *Musei i Pametnici za Kulturata (Sofia), 1981,* **4,** *34-9 (In Bulgarian).*

At the northern city gate of the ancient capital of Pliska three sunken huts were discovered during the 1980 excavations. One is interpreted as smithy (chisels, iron scrap, hearth); the other one contained punches and 60 copper fragments. The third hut may have been connected with metal working. Sickels, ploughshares and scythes represent finished objects. *CPSA*

T B Bartseva: Chemical composition of Antique Imported Objects found on the Middle Dnieper. *Sov Ark 1983,* **4,** *70-82. (In Russian).*

The author gives the results of 26 analyses of 26 objects and compares them with the metal of artefacts found in the Ukranian and Kuban Steppes. It was established that from the 6th to the 3rd centuries BC imported objects were cast from high-tin bronze, ductile bronze being used only for the mirrors of the Olbia type. The imported objects found in the middle Dnieper were made of ore from the Balkans and Carpathians. *Author*

A Burnett and P T Craddock: Rome and Alexandria. *American Num Soc 1983,* **28,** *109-119.*

Discusses the problem of coins bearing the name of a particular city, but coming from a central mint. Two groups of silver coins from Alexandria in the 3rd century AD were quantitatively analysed, one group made in Alexandria, the other apparently made in Rome. The finest is almost identical but all the Alexandrian coins were debased with copper whereas all the Roman coins with bronze. *PTC*

V D Gopak and A M Shovkoplyas: Iron Objects from the Zarybintsy Settlement at Obolon in Kiev. *Sov Ark 1983,* **4,** *154-60. (In Russian).*

The results of metallographic investigation of iron objects are given, dated to the 1st century BC to 1st century AD. The smiths used badly forged wrought iron. Steel artefacts are few. Heat treatment was used, as well as welding of iron and steel. Sometimes objects have been carburized.

Author (abridged)

P T Craddock: A Roman Mirror 'Discovered' in the British Museum. *Antiquaries Journal, 1983,* **63** *(1), 131-2.*

The silver mirror is in two parts disc and handle. Analysis showed disc has 92% silver suitable for hard brilliant reflecting surface, but cast handle is only 74% silver. A contemporary cast statuette from London found to have a similar composition, close to the eutectic. *Author*

C Davey: The Metalworkers Tools from Tell Edh Dhibai. *Bul Inst Arch, 1983,* **20,** *169-186.*

Detailed description and discussion of refractories ie pot bellows, crucibles, moulds (and covers), patterns and dishes. A very important group of 3rd millenium BC metal smelting equipment. *PTC*

P Fluzin, L Uran, G Béranger and C Coddet: Paleo-metallurgical activities. *In Université de Compiègne (France), 1982. (In French).*

An account of the archaeometallurgical research at the University of Compiègne centre established in order to study the iron weapons and other objects found at the ancient Celtic sanctuary at Gourney-sur-Aronde. One of the goals of the recent research is a better understanding of the problems connected with the ageing and long-term deterioration of metals, especially iron. Examples of results based on a wide range of methods used, experimental forging of lance butts. *CPSA*

B S Hall: Cast Iron in Late Medieval Europe: a Re-examination. *Canadian Institute of Mining and Metallurgy, 1983,* **76,** *66-71.*

The development of cast iron ordnance during the period 1400-1550 is compared with that of bronze, on the basis of available documentary evidence.

CPSA

H Horsch and I Keesmann Iron Ores from Settlement Site 8 at Langweiler, Germany. *Archaeologisches Korrespondenz-blatt, 1982,* **12,** *145-151. (In German).*

The Aldenhovener Platte deposits, according to mineralogical investigations, consist of oolithic oxide iron ores in the form of hematites including iron sandstones and red ochres and silicate ores. *CPSA*

W Hübener: A Study of Merovingian Period Battle-Axes. *Z Archäol Mittelalt, 1980,* **8,***65-127.* *BAA*

H Kars and J M A R Wevers: Early Medieval Dorestad, An Archaeo-Petrological Study Part III: A Trachyte Mortar, the Soapstone Finds and the Tuyères. *Ber Rijksdienst Oudheidkundig Bodemonderz, 1982,* **32,** *169-82.* *BAA*

L S Khomutova: Forging Technology among the Ancient VES in the 10th Century. (On the Materials from a Settlement at the Gorodishche Village). *Sov Ark 1984,* **1,** *199-209. (In Russian).*

The author discusses the results of the study of the forged products from a settlement at the Gorodischche village (Kirillov district, Vologda region, northern outskirts of Russia). The metallographic analysis of 90 objects, among which tools predominated has revealed the fact that the main technology was a combination of an iron base and a steel blade through welding. 60% of the objects were made with welded-in bars with welded-on blades, all-steel and all-iron objects. The author concludes that the technology of the multilayer welding of knives was exported from north western Russia probably from Staraya Ladoga where it was reported in a layer of the 2nd half of the 8th first half of the 9th century. *Author (abridged)*

G G Koenig: Shamans and Smiths, Physician and Monk: A Survey of the Archaeology of the Merovingian Medicine in the South Central Europe. *Helvetia Archaeologica, 1982,* **13,** *75-154. (In German).*

Among practising physicians of the Migration period were listed blacksmiths, by virtue of their ability to provide patients with prostheses (p 148). The study is devoted to general problems of health and medicines as reflected in archaeological material from that period. *CPSA*

F F Laures: Metal Nails from the Wreck at Palamos (Spain). *Int J Naut Arch, 1983,* **12** *(4), 343-4.*

Qualitative analysis shows that these nails that come from a ship sunk about 100-50 BC are of copper and bronze heavily sulphided. They are very variable in composition and condition which may be due to some being protected by the conifer wood of the ship and others being loose on the sea bottom. The copper and bronze nails were equally corroded. *RFT*

A Lundströmetal: Excavations at Helgö VII: Glass-iron-clay. *Stockholm, Almqvist and Wiksell, 1981, 177. (Paper: ISBN 91 7402 132 X).* *BA*

R Maddin: The Beginning of the Iron Age in the Eastern Mediterranean. *Transaction of the Indian Institute of Metals, 1982,* **35/1,** *14-24.*

Problems relating to copper smelting using ferruginous fluxes in early periods, the structures of iron meteorites on the basis of their nickel contents, and metallographical research of early irons from Palestinian sites (Tell Qiri, Mt Adir about 1000 BC). *CPSA*

E Kaszewska: On the Amber Route. *Z Otchlani Wiekow, 1981,* **47** *1-2, 26-9. (In Polish).*

A blacksmith's grave, equipped with tongs, hammer, chisel, files and iron wire from the Early Romano-Barbarian period, found at Zadowice near Kalisz, Poland, is mentioned in the paper. *CPSA*

A Rybová and K Motyková: The La Tène Period Iron Hoard from Kolín. *Pamatky Archaeologické, 1983,* **74,** *96-174. (In German).*

The hoard was found in 1936 but had not been published previously. It contained 68 iron artifacts (total weight 15kg) in the form of woodworking tools, agricultural implements, hearth equipment, knives and different types of mountings, including a large cauldron hook. It may be dated to a period shortly after 50BC. It was presumably a form of votive deposit. *CPSA*

D B Shelov: Roman Bronze Jugs and Amphorae in Eastern Europe. *Sov Ark 1983,* **4,** *57-69. (In Russian).*

The objects are dated from the 1st - 3rd century and were made by Roman craftsmen. They were found in the ruins of cities mainly in the Lower Don and Northern Caucasus (no analyses). *Author (abridged)*

L Kolto: X-ray Emission Analysis of Bronze Objects from the Avar Period. *Kaposvar, Hungary, 1982, 68pp. (In Hungarian).*

Surface and core analyses of copper base jewellery and ornaments mainly from the 6th to 8th century. Avar cemeteries to the east of Lake Balaton. About 1000 objects dated to the prehistoric, Roman and Middle Ages were examined. Some were silver or tin-plated. Most Avar material could not have been made by melting down Roman scrap. Many objects show appreciable Zn (10%) and most 1-2% Zn, but on the whole the Avar material is tin bronze with or without lead. Trinket moulds of stone are also discussed. *RFT*

P Northover: The Exploration of Long Distance Movement of Bronze in Bronze and Iron Age Europe. *Bul Inst Arch, 1982,* **19,** *45-72.*

The trace element composition of bronzes forms the basis of postulated trade routes across Europe. The article concentrates on Britain and Brittany. *PTC*

J Piaskowski: Hypothetical Reconstruction of the Characteristics Ascribed to Iron Smelted in the Ancient Region of Mazowsze, Poland. *Kwartalnik Historii Kultury Materialnej, 1981,* **4,** *433-450. (In Polish).*

On the basis of chemical analysis of slags originating in the Mazowzse bloomeries near Warsaw (mainly the early centuries AD), the author evaluates the quality of the iron produced. It is very rich in phosphorous (0.4-1% in the metal) and suitable only for a limited range of artefacts (knives, rivets, mountings not for swords, axes etc) because of its brittleness. Concludes that high quality iron must have been imported from the Holy Cross mountain area. Dephosphorisation with lime is technologically impossible in the conditions of the bloomery process; the calcium content of the slags is moreover extremely low. *CPSA*

N P Sorokina and M Yu Treister: Two Groups of Bronze Mirrors from the Collection of the State Historical Museum. *Sov Ark 1983,* **4,** *142-153. (In Russian).*

Seven bronze mirrors in the collection can be divided into two groups, differing from more common Bosporus mirrors of the 1st century AD. The first group consists of four rectangular mirrors, the other three are round. The mirrors have analogies among materials from sites of the Roman Empire and it is concluded that they were imported from Italy which is supported by spectral analysis of four mirrors. *Author (abridged)*

V I Vichlyayev: A Metallurgical Furnace from the Transition Period between 1st and 2nd Millenia AD at Mordva. *Sov Ark 1983,* **2,** *237-41. (In Russian).*

A pit containing some slag and burnt clay revealed some rather indistinct traces of a furnace or hearth, 50cm in diameter. Site: Novvy Usad III, upon the Moksa river about 1000 AD, connections to the Volga-Bulgaria. *CPSA*

O Voss: Iron Production, *in: Etruskens Verden, Nationalmuseet 1982 (Copenhagen), 22-6.*

Chapter on iron production in an illustrated book on the Etruscans and their civilization. Survey of the Etruscan smelting and mining activity at Populonia and on the island of Elba, where an estimated 2 million tons of bloomery slag must have been deposited before industrial re-use of early slag started in the 1920s. *CPSA*

F Widemann, K Gruel and J Lleres: Coriosolites: chronology, die Studies, Metallography, Experimental Blank Casting Related to the Trebry Hoard. *Archeologia, Oct 1982,* **171,** *11-20. (In French).* *BAA*

AFRICA

R B Gordon and N J Van der Merwe: Metallographic Study of Iron Artefacts from the Eastern Transvaal, South Africa. *Archaeometry, 1984,* **24** *(1), 108-127.*

A detailed investigation of iron artefacts, all surface finds, from Iron Age settlements at three hills. The specimens can be assumed to predate 1930. Metallographic evidence shows that the iron is almost certainly of African origin. All of the objects contain slag inclusions and some pearlite. Some of the objects are of homogeneous compositions throughout (over distances as great as 20mm) while others are highly variable over distances as small as 1mm. The inhomogeneity of the metal and the great variety of metallographic observed suggests that the metal in these objects originated from many local sources. *Author*

W A Oddy: Gold in South African Iron Age. *Gold Bulletin, 1984, 7 (2), 70-75.*

Gold artefacts from Mapungubwe and Zimbabwe and other Southern African sites were examined microscopically. Gold foils were carefully hammered out, beads were cast even those as small as 1.5 x 0.7mm in size. Wire was either made of strips twisted into a helix or made by hammering. *PTC*

AMERICA

Historical Notes – Early Ironmaking. Nine papers reprinted in 1983 as a pamphlet by the Canadian Institution of Mining and Metallurgy. Papers originally published in the CIMM Bulletin, May, June and July 1983, **76.** Issue numbers 853, 854, 855. *APG*

A Bérubé: Technological Changes at Les Forges du Saint Maurice. *Quebec 1729-1883, 1983, 3-8.*

After working unsuccessfully as a bloomery for a few months in 1734, a blast furnace and finery were in regular operation in 1738. Modernisation in 1846 enabled charcoal pig iron to be produced until 1883. *APG*

R S Allen: The Iron Industry of Northern New York, *28-32.*

The first bloomery was created at Skenesborough during the period 1764-69. Other bloomeries were followed by the first blast furnace in 1809, but the Adirondack Forge (bloomery) process dominated until the industry collapsed at the turn of the century. *APG*

C Andreae: Nineteenth-Century Nova-Scotia Iron Works, *1983, 12-17.*

At Londonderry, charcoal ironmaking began in 1855. Coke replaced charcoal from 1877 but after an unsuccessful attempt at Siemens Steelmaking, ironmaking ceased in 1896 except for a brief revival in 1905-1913. Open hearth steelmaking began at Ferrona in 1882 and coke ironmaking in 1891, but in 1904-5 the whole operation was moved to Sydney. *APG*

D D Hogarth: The Hull Iron Range 1801-1977. *1983, 18-27.*

Chiefly a description of ironmining in this area near Ottawa. One charcoal blast furnace produced a small quantity of pig iron in 1867-68. *APG*

K Inwood: Discovery and Technological Change: The Origins of Steelmaking at Sydney, Nova Scotia, *1983, 59-65.*

The difficulty with Newfoundland ore extended beyond its iron content and a resolution required more than the basic open hearth furnace at works based on high sulphur Cape Breton coal. *APG*

D J McDougall: The Grantham Ironworks, *1983, 53-8.*

In the province of Quebec, the first charcoal furnace at this plant was blown in at the end of 1880 and a second in 1881. Ironmaking ceased in 1911. The article emphasises commercial and economic considerations. *APG*

R R Potter: The Woodstock Ironworks, Carleton County, New Brunswick. *1983, 9-11.*

Low grade iron-manganese ore was smelted using charcoal in two blast furnaces 1848-1884. Some details of casts are given. Claims were made that wrought iron produced from the pig was very tough. *APG*

ASIA

H Bing-Gao: Casting in Ancient China. *Foundry Trade Journal, 1982,* **152,** *172-7.*

The paper deals with the casting of iron implements in iron moulds, which started after 450 BC. Huge iron castings in shape of lions etc from the 10th century AD. *After HM*

S Bunney: Zinc Smelting Began in India. *New Scientist, 8 December 1983,* **1387,** *739.*

Records the existence of very early zinc distillation at Zawar, Rajastan Mines dates back to 160BC by C-14. *PTC*

P T Craddock, L K Gurjar and K T M Hedge: Zinc Production in Medieval India. *World Archaeology, 1983,* **15** *(2), 111-7.*

Discusses the early occurrence of zinc production in India and the ancient remains at Zawar, Rajastan. *PTC*

P T Craddock: How Zinc was Smelted in Ancient India. *New Scientist, 29 March 1984,* **1403,** *23.*

Records the discovery of 16-18th century zinc smelting furnaces at Zawar, Rajastan. Thirty-six retorts fired for furnace, in banks of eight. *Author*

V D Len'kov and S A Sčeka: An Attempt to Determine the Raw Material Base of Chzuchzhenien Iron Metallurgy using Physico-Chemical Methods. *Sov Ark 1982,* **1,** *195-203.*

Chemical and quantitative spectral analyses of magnetite ores (>70% of Fe_3O_4), slags, and iron artefacts from medieval hill-forts of the Chzhurchzeni realm of Anchungurun (1115-1234 AD, Russian Far East Region of Primoriye) are compared with those of several important ore deposits. Comparative mathematical analysis shows that early ironmaking used small local magnetite deposits outside the areas exploited in more recent times. *CPSA*

V C Piggot: The Adoption of Iron in Western Iran in the Early First Millenium BC: An Archaeometallurgical Study. *Dissertation Abstracts International, 1981,* **42/3,** *321.*

Iron found its way into ancient Western Iran during the 10th-7th centuries BC. Important role of Hasanlu site. Metallographic examination (8th century BC) revealed mostly wrought iron or heterogeneous carbon steels. *CPSA*

W Rostoker, B Bronson, J Dvorak and G Shen: Casting farm Implements, Comparable Tools and Hardware in Ancient China. *World Arch 1983,* **15** *(2), 196-210.*

Beginning some time before the 5th century BC and continuing thereafter, the Chinese developed a process for producing molten cast iron which they applied to the manufacture in large number of implements, tools and hardware. Mass production techniques utilizing cast iron permanent moulds and stacked clay moulds are described. The tools were composites of working tips or heads of metal and wooden handles attached as a slipper fit or through a socket hole. Some degree of toughness to resist cracking or spalling was imparted by heat treatments of the cast iron. The availability of such tools for agriculture, road and canal building, mining and quarrying must have provided the basis for urbanization and national organization. *Author*

A Smith: A History of Tin Mining. *Tin International, 1982,* **552,** *48-53.*

Comprehensive descriptions are given of the primitive panning, ground sluicing, mining and smelting methods used for Sn winning and extraction in the Malay archipelago and of their improvement by Chinese interpreneurs in the early mid nineteenth century. This involved relatively sophisticated uses of water power and sluice boxes and the introduction of superior smelting equipment and techniques. The supremacy of the Chinese is attributed to their character and nature of their secret societies which significantly influenced the Malayan operations. *AATA*

R F Tylecote: Ancient Metallurgy in China. *The Metallurgist and Materials Technologist. September 1983, 435-9.*

Metallurgical evaluation of the Han period blast furnaces at Gu Xing. The possibility of blowing preheated air through a composite tuyere system is suggested. The 20t bear contains 0.73-4.52% C. The invention of the Chinese indirect process is ascribed to the accidental very high fuel/ore ratio. Finery processes, pilling and folding technologies in making blades (Shandong knife, AD 112) are discussed. The bloomery and blast furnace processes were operated simultaneously in ancient and early China. The traditional form of zinc distillation in a vertical retort is illustrated. *CPSA*

E Kaptan: The Significance of Tin in Turkish Mining History and its Origin. *Bulletin of the Mineral Research and Exploration Institute of Turkey, 1980-81,* **96-96,** *106-114.*

Progress in research into the history of Sn mining in Turkey and patterns of trade with Mesopotamia in the second millenium BC are reported. *PTC*