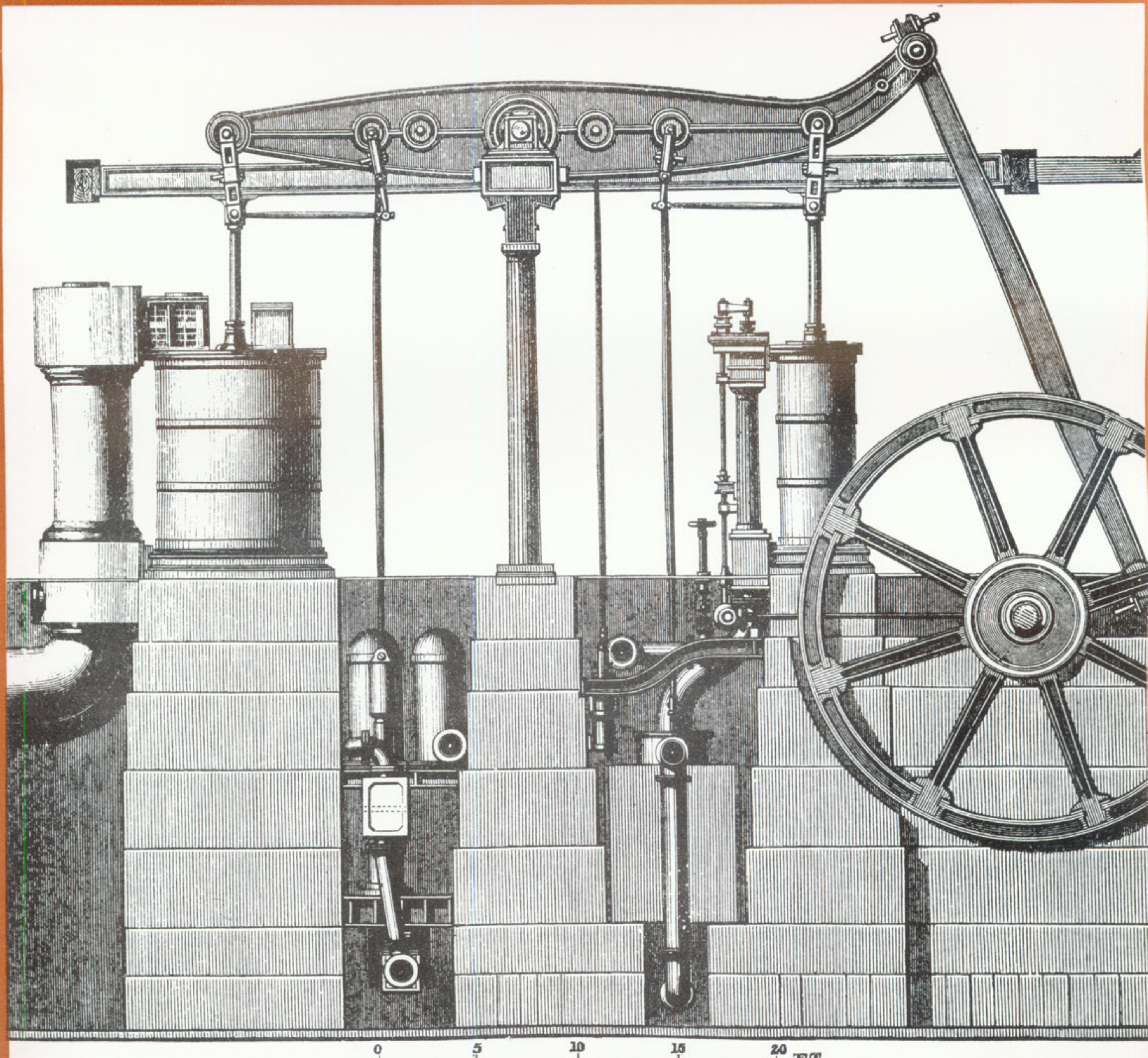
HISTORICAL METALLURGY

Journal of The Historical Metallurgy Society Volume 8 Number 2 1974



Blowing engine, Shelton Colliery and Iron-works. Side elevation.

Journal of the Historical Metallurgy Society

Formerly the Bulletin of THE HISTORICAL METALLURGY GROUP, the name of this publication and of the Group was changed in 1974 when the merging of the Iron and Steel Institute and the Institute of Metals resulted in THE METALS SOCIETY, which THE HISTORICAL METALLURGY SOCIETY is associated with. The numbering of volumes has remained unchanged.

Enquiries relating to the contents should be addressed to the Honorary Editor:
Dr R F Tylecote, Department of Metallurgy, The University of Newcastle upon Tyne, Haymarket Lane, Newcastle upon Tyne NE1 7RU.

Enquiries concerning membership of the HMS, back numbers and subscriptions to the Journal, etc, should be directed to the Honorary Treasurer: Charles R Blick, 147 Whirlowdale Road, Sheffield, S7 2NG.

Contents

Published by THE HISTORICAL METALLURGY SOCIETY

Produced by R Day, Honorary Production Editor, Parsons Brown, Brigstowe, Welsh Back Bristol BS1 4SP

Designed by John Doggett MSIA

Typesetting (IBM 9pt Press Roman) by Mrs M Earl and Mrs E M Jefferies

Printed by THE METALS SOCIETY, 1 Carton House Terrace, London SW1Y 5DB

The illustration on the cover shows one of the condensing type beam engines built by the Haigh Foundry Company of Wigan in the early 1860s to supply blast air for the iron smelting furnaces at the Shelton Colliery and Iron-Works near Stoke on Trent.

Reproduced from Percy's Metallurgy, Iron and Steel, published in 1864.

A Seventeenth Century Manuscript:

Notabilia in Essays of Oars and Mettals

by my own Labour and Experience, with a good Number of other Artist's Experiences & Secrets by communication and own Remarks upon it with many nice secret Observations in time Collected and brought now into this succinct way and Order very Intelligible

An Essaye upon a Fusible Silver or Gold Oar.

Take a Hundred (which we will stile by the Latin word Cent) of the Oar, powder it small add to it 7 Cent of Granulated Lead, mingle it together, put it upon a dry Test, put it into an Essay furnace and cover it with its muffle, now cover it with Charcoal, and some live Coal a top of that, that the Fire may kindle downwards to warm and to heat things by Degrees, put likewise some Coal before the Fire plate, pull the Door of the Ash-hole open to afford Air, and to bring the Fire to a due heat, but when the Oar begins to rise and to Drive (to copple) then take away the Coal before the Mouth and shut up the Ash-hole and your Oar does roast it self and goes into the Lead, this done make it to stand as warm again as before and stir it about with an Iron hook at the end of a Rod (but warm'd before hand of a Cherry red heat) and when you see that it is now well sunk and imbibed into the Lead, pour it out into your Cone, let it grow cold and knock of the Scories.

When you have ready a Coppell made of Bone Ashes place it into your Essaye Furnace under a Muffle, kindle your fire and heat your Coppel till it becomes all over throughly red hot, then carry your Regulus upon it and put Coals before the Mouth & shut up the Ash hole till it begins to drive, then open it again, &c and take off one coal and let it Coppell off with a considerable heat, till it comes to a Blick, and that is your Silver corn

30.5 cm

NOTABILIA IN ESSAYS OF OARS AND METTALS

A Seventeenth Century Manuscript:

by Cyril Stanley Smith and Barbara Wallraff
Massachusetts Institute of Technology

The manuscript transcribed below *(now in a private collection in Cambridge, Massachusetts)* is of special interest because of the dearth of technical source material relating to English metallurgy in the seventeenth century.[1] The **Notabilia** covers the smelting and refining of copper on a commercial scale in addition to the laboratory assay of silver, copper, lead and tin ores, with some mention of iron and occasional references to gold. Though the author deals with many of the same processes that are described in the classic continental works by Biringuccio, Agricola, and Ercker, his descriptions are independent.

The manuscript bears no record of its authorship or date of composition. A note on the fly-leaf states that it was purchased on March 25th, 1700 for the sum of 3s. 6d. by Ja*(mes)* Stanley, undoubtedly the tenth Earl of Derby, for it bears a shelfmark from the Earl's library at Knowlsey Hall near Prescott, Lancashire. The text occupies one side only of each of fifty-five leaves in a vellum-bound book that was evidently originally a stationer's stock item, for each page has the four vertically-ruled columns appropriate for an account book. The folio sheets are of good quality paper folded to leaves measuring 31.5 x 19.8 centimeters, gathered into six signatures containing altogether sixty-six leaves.

The manuscript is easily legible, but occasionally misspellings of common English technical terms and the frequent misreadings of German ones suggest that it had been transcribed from a carelessly written original by an amanuensis unfamiliar with its technical content. Professor D.S.Berkowitz, who has examined a photograph of the manuscript for us, says firmly that it is in the hand of a professional scribe working in the second half of the seventeenth century. One of the two watermarks on each double-leaf sheet of paper is identical with that in a book printed in Amsterdam in 1668.[2] All of this is in accord with the technical content and suggests that Stanley's purchase on 25 March 1700 was of the completed manuscript, not of the blank book which, in any case, would not have been so expensive. We believe that the date of composition was approximately 1675.

The illustrations, which appear in the text wherever called for by the content, were lightly sketched in pencil and then gone over, not very skillfully, with ink. The author was beyond doubt German, for he falls back on German terms when he is uncertain of the English, and in one place *(p.16)* specifically says "as we terme it in the German tongue." The blast furnace is the **Stich** furnace, its taphole the **Anzug**; it is lined with **Gestube**, and it somehow produces **Jahtkupfer** *(=* **Garkupfer**, *refined copper)*. A material commonly used as an addition or smelting flux *(***Zuschlage**, *or a misreading thereof)* is "lettoon", apparently a corruption of the German **letten**, for on fol. 27, it is described as a kind of fat yellow loam or earth that turns red on roasting.

English spelling at that time was, of course, pleasantly variable, but the spelling lytharidge for litharge and traff for trough used throughout the manuscript are not listed as variants in the OED. Though **seigern** and **sichern** are correctly used in the text for liquation and for ore-washing respectively, when they are specifically defined on fol.26, they are inverted! **Speise** is translated as meal, rather logically but improperly in its metallurgical use, though it refers to a matte, not a true speiss.

There is no doubt that the author is writing from his own experience on most matters, for he includes many little practical comments that no mere observer would regard as important. Technically, most of the operations described are little different from those published in sixteenth century treatises and need little comment. The assay weights were miniature models of the legal system so as to render calculation of the results unnecessary. The scaling ratio was 1/7000, making a hundred grains to represent 100 pounds. The washing and levigation of ashes for cupels, their shaping in male and female molds *(friars and nuns)*, and the use of muffles with holes cut in the sides *(Figure 2)* could be of almost any date after the Middle Ages, yet there are a number of points that suggest a date of about the middle of the seventeenth century.

Some experiments are recommended not for profit, but simply for the pleasure of seeing the outcome – an attitude that any experimentalist will applaud. There is the usual emphasis upon the roasting of ores for assay and on the proper use of fluxes, but the classic black flux, lead glass and iron filings are supplemented by the use of lead arsenate and the deliquescent residue *(calcium chloride)* left from making ammonia.

The author often adds a word or two of theory to account for the efficacy of his procedures. In this he is a forerunner *(albeit a feeble one)* of J.A. Cramer whose **Elementa Artis Docimasticae** *(Leyden, 1739)* was the first published assay book to illuminate assaying practice with theory. He knows about atoms and acids and alkalies. Thus, iron, being of a porous alkaline nature, can break the acid points of the "wild sulphurs" in the lead ores, imbibing them and so releasing the metal to sink to the bottom of the crucible by its own gravity. It is suggested that sulphide ores may be treated with lye to remove the sulphur and so open them up for acid treatment: they must be well washed before the last stage or else the points of the acid will blunt themselves on the alkaline lye and not work on the metal.

Lead glass, commonly used by assayers as a flux, is regarded as a solvent in which chemical reactions take place, much as in the commoner reactions, for he sees that silver chloride, lead sulphide, copper sulphide, and litharge all yield up their respective metals when the acid parts combined with them are transferred to some more active attractant.

The pointed acid parts smack strongly of the seventeenth century corpuscular philosophers, the sulphurs of Van Helmont, and the alkalies of Glauber and Boyle.

More important, there is a hint of the wet methods of chemical analyses to come in the extraction of iron from its roasted ores with spirits of salt *(hydrochloric acid)* and testing with gall *(the old ink reaction)*, and the extraction of calcined copper with spirit of salammoniac *(ie ammonium hydroxide)* which gives a blue solution *(fol. 29)*. Both of these reactions were first used in qualitative analysis by Libavius. Not satisfied with just describing the treatments of salt to prevent its decrepitation when used as a flux, the author says why, clearly and correctly. The black residue left after nitric acid treatment of auriferous copper is burnished to demonstrate that it is yellow gold. The spattering that is observed during the reduction of lead oxide to the metal *(fol. 5)* is possibly the earliest record of the effervescence that, **inter alia**, later led Lavoisier to the discovery of the nature of combustion. The use of a microscope on clay ironstone is referred to offhandedly. The author is aware of the relationship between the crystalline appearance of an ore and its richness, for he expresses surprise that a "wild antimoniac sort of a lead ore" with coarse points, flakes, and shining angles should contain 29 pounds of lead and 6 ounces of silver per hundred weight.

The description of the construction of the blast furnace for the large-scale smelting of copper is straightforward and in fair detail, though no mention is made of any mechanism to power the bellows. It will be noted that the author insists on a ventilation vault in the foundations to prevent the rising of ground water, and he recommends the lining of the furnace with **Gestube** *(brasque)*, more for convenience of repair than necessity. When smelting copper, fluxes of iron ore, **lettoon** *(loam)*, and limestone are used, and the metal is put through the furnace three times with one intermediate roasting. In starting up the furnace, it is necessary to have a blank run to make some iron slag to mix with later ore charges, and the slag from these is reused until it loses its glassy appearance – a fair index of silica content. The refining of copper in a separate hearth is described casually, almost as if it were cupellation (*to which, of course, it is somewhat analogous),* and there is no mention of the poling operation that would be necessary. The recovery of values from sweepings and miscellaneous waste is well treated.

The organization and operations of the English copper industry in the sixteenth century are discussed in detail by M.B. Donald,[3] and in broader perspective by H.Hamilton.[4] Queen Elizabeth had encouraged the Mines Royal Company to import German metal-workers to work the English ores. Although most of them had returned before the end of the sixteenth century, the German author of the **Notabilia** may have been a descendant of one of the original immigrants – this would account for the use of German terms in otherwise relatively fluent English – or possibly the work in its present form is a transcription of a much earlier notes with the addition of some modernizing paragraphs.

The only works in English comparable to the **Notabilia** are two items published by Donald – excerpts dealing with the assaying of copper and tin ores from the note-book kept by Daniel Hochstetter in Keswick in the 1560's;[5] and a 1581 letter by George Nedham[6] criticizing Hochstetter and advancing the views of another German consultant named Joachim Gans, who properly identified the nine "evil and hurtful humours" present in the English ores that were making the operations on them so profitless. The **Notabilia** gives much more technical detail than either of these notes, though it is unimportant compared with the earlier period works of Agricola and Ercker, for example, or the later ones by Cramer and Schlütter. All these are continental, while the manuscript provides an insight into the mind of a man working in England at an important, if briefly depressed, period in the development of the metal industry.

What follows is an exact transcription of the manuscript, or at least as close a transcription as is possible using a typewriter which does not permit nuances of letter size to denote initials and varying emphasis.

Production Editors Note

It was the express wish of the Interpreters of the **Notabilia in Essays of Oars and Mettals** that their original typescript be used direct for publication.

The Journal of the Historical Metallurgy Society is normally set in 9pt Press Roman on an IBM Selectric Composer using a 3¼ inch column width but as the manuscript in question was typed to a 5½ column width it became necessary to use a photographic process which has resulted in an image size some 40% smaller.

The illustrations Figures 1, 2, 3 and 4 are reproduced actual size and in fact photos taken from the original document have been used as 'masters'. Figure 5 has been subjected to the same reduction as the text material. The frontispiece to this article page 75 is also a full size photograph.

Notabilia in Essays of Oars and Mettals

by my own Labour and Experience, with a good Number of other Artist's Experiences & Secrets by communication and own Remarks upon it with many nice secret Observations in time Collected and brought now into this succinct way and Order very Intelligible

An Essaye upon a Fusible Silver or Gold Oar.

Take a Hundred (which we will stile by the Latin word Cent) of the Oar, powder it small add to it 7 Cent of Granulated Lead, mingle it together, put it upon a dry Test, put it into an Essay furnace and cover it with its muffle, now cover it with Charcoal, and some live Coal a top of that, that the Fire may kindle downwards to warm and to Heat things by Degrees, put likewise some Coal before the Fire place, pull the Door of the Ash-hole open to afford Air, and to bring the Fire to a due heat, but when the Oar begins to rise and to Drive (to copple) then take away the Coal before the Mouth, and shut up the Ashhole and your Oar does roast it self and goes into the Lead, this done make it to stand as warm again as before and stir it about with an Iron hook at the end of a Rod (but warmd before hand of a Cherry red heat) and when you see that it is now well sunk and imbibed into the Lead, pour it out into your Cone, let it grow cold and knock off the S ories.

Now have ready a Coppell made of Bone Ashes, place it into your Essaye Furnace under a Muffle, kindle your fire, and heat your Coppel till it becomes all over throughly red hot, then carry your Regulus upon it and put Coals before the Mouth & shut up the Ash hole till it begins to drive, then open it again, & above take off one coal, and let it Coppell off with a considerable heat, till it comes to a Blick, and that is your Silver corn

Now to know exactly what a Cent holds you must Coppell likewise 7 Cent of the same Lead by it self to see if that holds any silver and how much it holds, and if it does, that same must be added to the Silver corn, and then you may make your Calculation in Great.

Or make use of this second Method. Viz^t
Take your Oar either Solar or Lunar, calcine it, that is to say Toast it up a Dry Test under a Muffle, then take 2 parts of Lytharidge & double the quantity of the Black Flux and [p.2] and reduce it by melting it in a Crucible into a Regulus, then you have nothing to do but to put this Regulus upon a Test and to Coppell it.

Again a Third method Viz^t
If you have an Oar be it what Oar it will and that you suspect or want to know if it holds Silver. Take of the Oar one part, Pulverise and roast it under a Muffell to chace away the Wild Sulphurs, and add to it 3 parts of Vitrum Saturni (Glass of lead) both in powder make it come to melt well in a Crucible in your wind Furnace, then add some Iron or Coal dust to it, and that does praecipitate a Regulus, about an Ounce or half an Ounce of Mars is enough to about a pound whith Regulus is the Lead that was reduced out of the Vitrum Saturni and what Silver now was in the Oar, is then in Lead, so that you have nothing else to do then to put it upon a Test and to Coppell it, and you will see what you have.

Note, if your Oar be rich enough, the Black Flux without the Glass of Lead is then sufficient, that is to say take 2 parts of the Black flux to one of the Oar and bring that to a good Fusion in a Crucible, and there will be a Regulus at bottom Again, observe if you find that your Oar is too Stony, then take only instead of 3 parts vitrum Saturni only 2 parts of Lytharidge, because the Lytharidge being more naked, that is to say, not yet charged with another Corpus it takes in (swallows up) the Stony part, and Scorifies the Oar, so that the Oar must yield its Regulus very conveniently. But Note, when the Lytharidge with the Oar is well in Flux it must be praecipitated with a little Iron Filings or Coal dust which by guess you scatter upon it

Remarks

Note when I speak of a Cent or hundred weight you must not understand a 100 of large Weight, but by that word Cent (a Cent or a hundred) we mean that we have small Weights that is called a Cent, that is already calculated & Divided ready to your hand from the large hundred weight into a small hundred, that is to say take instead of a 100 pound hundred graines and them graines signifye your your whole Pounds but that the Calculation from the little to the great may be just and to agree we have those curious Essay Scales that draw so sharp that the least dust is able to make the Scale turn, for which Reason they are kept always in a close frame like a Box or Cupboard with glass Window & glass door to it to save it from dust or the draught of Air or Wind

Note what I mean by Granulated Lead is as follows. Take some Lead what quantity you please melt it in an Iron ladle then put it into a Wooden Trough which has been rubbed before hand with a piece of Wax but mind as soon as you see that the lead grows a little stiff swing it up & down very quick as fast you can, as they do swing Oates for Horses in which Fatt it breaks its self all into small Bits and Atoms which we keep by us ready for use in a Box.

Note that the use of vitrum Saturni or the Lytharidge is only used as the Remedy for poor Oars where the Mettle is but few and but poorly scattered betwixt so much Earth or Stone for the Vitrum Saturni to the Stony Oar is to be considered as its water or vehicule the same as water is the vehicle to Boyle Flesh or Herbs to a pap which if it has not water enough, it Boyles only into Nobs for want of Moisture to extend it self enough therefore the Vitrum Saturni is the Vehicle or Water to desolve the Oar or Mettle.

Note, if an Oar be more stubborn yet as per Example in the Oar called Cobaet oar then the vitrum Saturni made with Arsenic serves best, for Arsenic makes a terrible Fusion and penetrates all things it is so devouring, and this vitrum you make with 3 parts of Minium and 2 parts of Arsenic and no Sand or Pebble stones there, but it is apt to bore through the Crucibles. Therefore you must have care or take 2 Crucibles one set into the other

Note if so be that the vitrum Saturni is become greenish in melting with your unknown Oar where you suspect Gold, then you may conclude that it contain Gold for a Yellow & a Blew makes a Green.

Note here, by way of Curiosity that you take notice of a hint, that in making your vitrum Saturni you use instead of Sand white pebble stones, for they are of themselves a little Goldish, but you must only use the White ones and that have veins and keep white after Calcination, but others that become black in the Calcination are nought and Martial, for before you Powder them they must be made red hot in the fire and quenched in Water, then you take one pound of them powdered and 3 pound of Minium then melt them in a double Crucible for it is apt to penetrate and to bore.

Note, if you meet with an Oar that is less Fusible that is to say Harder (more stubborn &c.) then take instead of 7 Cent of the granulated Lead 9 Cent to one of the Oar, but then you must likewise Coppell 9 Cent of the Lead by it self, that what Silver those 9 Cents leave (if it has any) may be added to the Silver Corn, that you may be well assured of the exactness of your Trial as is already mentioned.

Note, but if you meet with a very stubborn Harsh Unfusible oar indeed that is harder yet and will not go into the Lead, but lodges upon it like Ashes, then use upon it 1/4 Cent of this following Flux, and that will force and finish it Viz^t Take 2 parts of Lytharidge and one of your best white and shining Pebble stones (I mean that break white because there be others that look brown like Iron within & these to reject) beat fine into Powder and put into a Crucible, let them come to a good thin Fusion in your melting Furnace, then break the Crucible as soon as it is cold and you have at the bottom a little Regulus which you put by and take only the above swiming Scories, Pulverise and sift them, & keep them in a box always ready for use, of which you take 1/4 Cent, and put it as already said upon the above mentioned Essays. Note, you must mix the Flux with the mixture before it goes upon the Test and it is better still, that is to say if you guess that you have such a stubborn Oar.

Note, sometimes it will happen (tho' but seldom) that you think all is gone into the Lead, you shall find between the Scories and the bottom a congealed matter, that did gather there which is yet Oar and Scories together that was not perfectly sepperated In that case seek to rake it out from thence with an Iron rod a hook at the end and rub it small, and mix a quarter Cent of the aforesaid Flux with it and so put it upon the Test, and it will then go in as the rest.

Again some of this Oar is of the nature that it looks as i. it had been boiled (as we term it) upon the Test orderly well (because as Lead is the water for Mettles it is called Boyling) and yet sticks to the bottom of the Test, which you easily feel with your Hooke, for it will stick to the Hook very close as not to come off easily in that case your Remedy is to take caput mors of Aqua fortis which the Chymists have and throw away that same beat to Powder, and put a little upon the Test and it loosens it self off from the Test and does as the other Oar.

Again, another nice Observation is, that it may happen in some of these kind of Oars (of which there is variety) that though you have very regularly boiled them upon your Test, that yet when you bring it afterwards upon the Coppell for Coppelling it,it turns upon the Coppell into Scories, and you will find no Silver. The remedy for this is, when you have thus Boyld (as we term it) the Oar in the Lead, knock off the Scories from it, and put it again upon a new Test, and let it Boil up again once more, set it then again upon a Coppell and it will Coppell off well and Neat as any other sm. Oar, and take here notice, that these like Unfusible Oars you pour not out into a Cone after they are boiled upon the Test, but let them cool upon the Test in the Furnace, & knock a little to the Test, and it settles and gathers it self well to a Bead or Center otherwise there is Bubbles in the Scories, so that by these several means (of heating Oars) and Observations you have here a full account agst All sorts of Accidents as they happen of what Oar soever you meet with provided you make your self Master or Artist enough of the Degrees of Fire and to understand your Furnace well (which is only use) and consequently you will by these Essayes have a full knowledge of the nature of the Oar which without these Essays could not be known.

Note, if in Fusions of Silver or other Silver processes your Crucible happens to crack, and to run through or that there be graines of Silver scattered up and down the sides of the Crucible then powder the Crucible and the rest pick up out of the Coals, and take of this powder and of Lytharidge to it equal parts and about the 4th part or less of the following Flux Viz^t Tarter, Nitre, Salt, and Filings of Mars of each equal parts. This Flux together with the Lytharidge does gather the Silver again, and brings it to a Regulus and then you have only to Coppell it and to sepperate the Lead.

Item, if it happens that you have Experiments in hand upon Silver with Copper and Lead and that there be too much Copper and too little Lead with it I mean when it is upon the Coppell, you must expect that it will drive or Coppell well for a while with Flowers (as usually Copper & Silver does) while there is any Lead but at last it will not drive at all. Note, the reason of it is, that the process abounding in Copper, the Copper went or Bored into the Test (which Copper is apt to do unless it has a great deal of Lead) so that it is always a good Observation to lay (in such processes) first some per per see upon the Coppell and let it drive before the Copper mixture comes upon it, that the Lead may take up the first place in the pores of the Bone Ashes in the Test, for though you should put more Lead afterwards (as the usual [p. 5] Remedy Artists can do) it signifyes nothing, for all what the Lead does do then, is that it turns only into Lytharidge.

Now note, that you may have a trick or remedy in that too, when you have been catched so Vitrifye your Lytharidge with sand (according to the method in the Lead process) and then precipitate it with Nitre and Coal dust. Note precipitating with Nitre and Coal dust is thus Viz: when sand and Lytharidge are brought to Fusion you put Nitre upon it and let that flow too and stir it with an Iron rod about to mix it, then put a little spatula full (but all by degrees) of Charcoal dust upon it, and it and works, then more Coal dust upon it till it works or Spotters no more, and the Mettle part seperates and it is no more Glass but a Regulus at the bottom. Note, the way of reducing any Calxes of Silver or that Calx which is called Luna Cornua is as follows Viz! set some Lead adriving upon a Coppell and there carry your Calx of Silver, or your Luna cornua upon it, and the Salts (that kept the Silver disguised as to make a luna cornua) are seperated, and the Silver reduces leaves the Salts & goes into the Lead immediately. Or to reduce it another way, take 2 ounces of Vitrum Saturni powder it and mix with it an ounce of Luna cornua, let it come to then some Nitre upon it, and when it is in Flux, scatter some Charcoal dust upon it till it is saturated, I mean till it makes no more Detonation and you will find your Silver at the bottom.

Item, Luna Cornua is likewise reduced by melting it and droping upon it Fat or Tallow till it grows hard & a little Nitre and Charcoal dust after it or Burras to melt it down for the Fat or Tallow is of an A nature and therefore imbibes (sucks up) the Aridity that kept the silver in that disguise.

Note, the least bit if Jupiter that chances to get amongst Gold makes it become all brittle & fall to pieces.

Note Iron Vessells are not good to be used in Preparations or Tryals where there is any Gold in it, for it is apt to leave other mixtures and get to the Iron and a Virtuoso told me that it even turns it into Glass and destroys it [p.6]

An Account of Cuppeling & makeing of Cupells with many Nice Observations & Curiosities in this Art to Coppell well & to understand the true nature thereof

Note: The first thing belonging to Cupelling (Testing) is to have good bone ashes that are well burned or calcind till they are become perfectly white & light in the fire For those bones that are yet hard or look Yellow must be pickt out from the rest & burn'd again a Second time till they become white & Soft as the rest These must be powdered & Sifted very Small & kept tyed up or Shutt up in boxes or potts to Secure it from Catts Piss or Turdes or Other Filtheness but as these Ashes will lump and Cake togather in time because of the moisture of the Air. Now when you have occation to make Cupells (Tests) pass your Ashes againe through a Sive a new, then take Some of them into a dish & moisten them with fair water no more then just to make them Clammy that they may ball between your hands but that the least touch of a Childs finger may make it fall to pieces again

Now take these clammy Ashes & cram them (press them) hard down into your brass Coppell Mould (as follows) called Niens, then upon that fix or place your Uppermost Mould (called the Fryar) up right perpendicular & give 2 or 3 equall knocks. Tap Tap Tap upon it with a hammer & your Cupelle is made. then to get it out of the Nunn turne it topp side down, haveing a piece of an old hatt or thick flannell or other piece of Woollen Cloath under it & with your thumb or ye ball of your hand, Trust or press down upon the Niens & that fetches out ye Cupell of which cupells or Tests you make allways a good Number & of all Size's according to the following Figures to keep [p.7] ready by you & to Lett them have time to dry well in the aire or near Some Small Warmth or other

Note that by blowing upon it & with a pen knife you take of what ashes is loose upon the Test & about ye edges. [Fig.1]

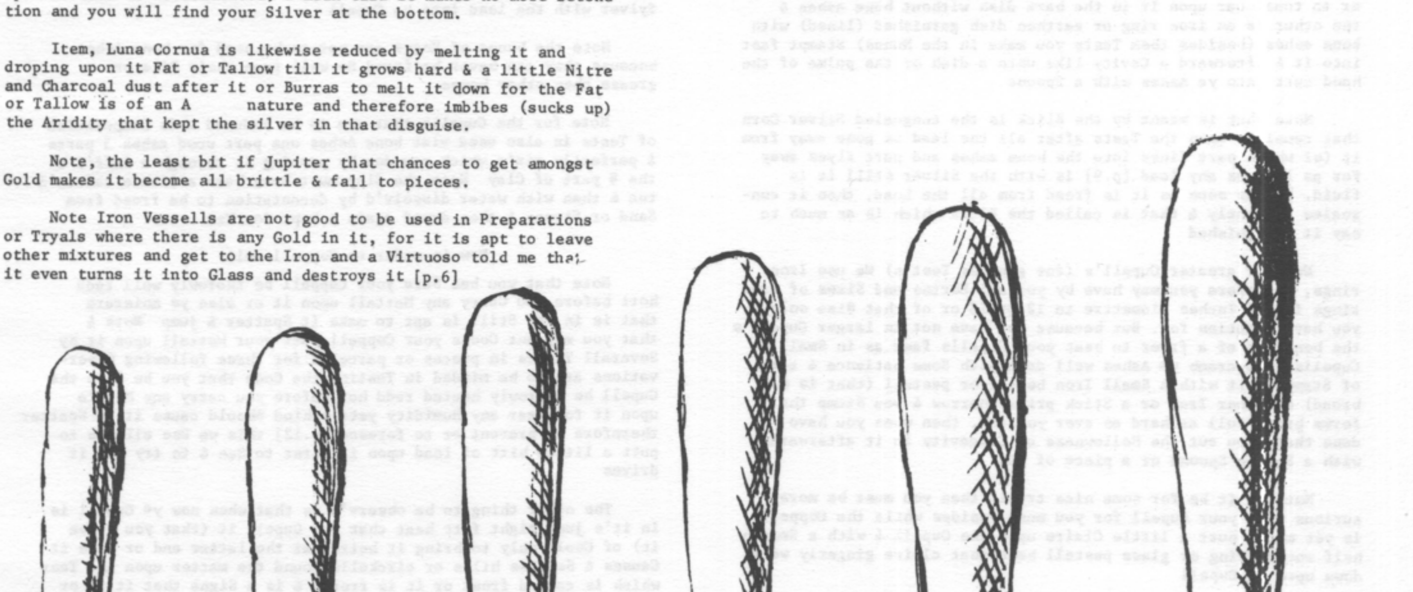


fig1

Note that what is called the Muffell is a flat piece of Dow of Clay turned into the forms following & is made of crucible Earth & may be done also with Sturbridge Clay & it is that w:ch covers the Test in the Essay Fournace to keep the Coals of from the Test at the sides it has holes cutt in it that the heat of ye fire may Circulate the better into it, behind it is Shutt up but open before as you See on the Side represented, partly with their front this way & partly with their back part out One open & the back part close.

fig2

[p.8, Fig.2] Note what is meant by a Cone is a brass or Iron mould like unto this [Fig.3] vizt that what is cast into it is of a Piramidall forme & that for two reasons the One that the matter that is cast into it may the easier Slip out again by a Slight knock upon the Floor the other reason is that haveing a taper point or Centre the Reguly [reguli] of your mineralls. Sinks the bettere to the bottom & is the easier seperated from the Scorys, which because of their lightness swimes allways a top Note that this Cone is allways greased with oil or Candle grease first before things is cast into it.

fig3

Note what We call a dry test is only an earthen Dish made of good crucible or other earth like unto a Test (Coppells) The Difference of which dish & Cupells, is, that ye Use of one is to melt or to toast oar upon it in the bare dish without bone ashes & the other is an iron ring or earthen dish garnished (lined) with bone ashes (besides them Tests you make in the Nunns) Stampt fast into it & afterward a Cavity like unto a dish or the palme of the hand cutt into ye Ashes with a Spoone

Note what is meant by the Blick is the congealed Silver Corn that remaines upon the Tests after all the lead is gone away from it (of which part Sinks into the bone ashes and part flyes away For as long as any lead [p.9] is with the Silver still it is fluid, but as soon as it is freed from all the Lead, then it congeales presently & that is called the Blick which is as much to say it is finished

Now for greater Cupell's (for greater Test's) We use Iron rings, therefore you may have by you all Sortes and Sizes of Iron rings from 4 Inches Diamettre to 12 or 18 or of that Size only you have occation for. But because you have not in larger Cupell's the benefitt of a fryer to beat your Cupells fast as in Small Cupells, you cramb ye Ashes well down with Some patience & time of Stamping it with a Small Iron beater or pestell (that is not broad) or other Iron or a Stick pritty narrow & you Stamp the forme brimb full as hard as ever you can, then when you have done that, you cut the Hollowness or Concavity in it afterwards, with a Sharpe Spoone or a piece of Tin

Note if it be for some nice tryall then you must be more curious with your Cupell for you must besides while the Coppell is yet moist putt a little Claire upon the Cupell & with a Smooth half round thing or glass pestell beat that claire gingerly well down upon ye Cupell

Note you putt the Claire into a Sive & knock gingerly upon the Siff & that does spread your Claire every where even alike upon the Cupells and in this manner you Serve likewise ye foregoing Cupell's made in the Nuns what is designed for a nice tryall but

Note what we call Claire is nothing else butt good Bone ashes ground extreamly fine upon a porphire for it is to Stop all the pores of the other Com̃on bone ashes upon ye Cupell which are never made so Small as the Ashes [p.10] for the Clair. it is need to have the Clair exceeding fine & to be more curious yet with your Clair it ought to be made of Softer bones then the usuall common bone Ashes espicially in nice tryalls. Such as calcin'd fish bones if not you must content yourself with Calves foot bone Ashes provided you make them fine enough

Note if you will be counted a Curious man indeed for good Cupell Ashes, the Secrett is, that when the bone ashes are calcin'd & powdered, to wash them with Severall waters to free them perfectly well from all its Salts, then to burne them over again a Second time & wash them again a Second time & then dried & kept ready by You for use and that Secrett Essay Masters generally conceal espicially what Serves for Claire ought to be Serv'd So & that Serves them for very Curious & exact tryalls

Note all the Self Same thing is done with com̃on bakers Ashes (wood Ashes) that is to Say to Shiff't them, to wash them & burne them & wash them over again a Second time but Note that ye last time in washing, you pore the ashes of by decantations, that all & every heavy Sandy Stony part be freed from it to remaine behind & to be rejected

Note that ye Use of these wood ashes for Cupell are Some thing different from bone Ashes that is when you have Occation for great Tests which you want afterwards to reduce, the bone Ashes do not reduce So well or you take two parts of wood Ashes & one part of bone Ashes to make your Tests but for Small exact tryalls all bone ashes is better & the difference between the bone Ashes & the Com̃on [p.11] Ashes are, that ye Wood Ashes drives of sooner but the bone ashes later & purer

Note Sometimes we likewise use a little Clay with it (that is to Say) when we have to deale with Sulphurey Oars or other Sulphurey things that are apt to bore into the Tests & to penetrate as those doe that have much Copper for that Carries the Sylver with the lead into ye Cupell

Note the bones of Hoggs are not to be used for bone Ashes because they can never be freed So well from their Oile or grease then other bones

Note for the Cupells that are to be reduced this Composition of Tests is also used vizt bone Ashes one part wood ashes 3 parts & perfectly mix't which you doe by passing it through a Siff't & the 8 part of Clay Note the Clay must have been a little calcin'd too & then with water dissolv'd by decantation to be freed from Sand or Stones & then dryed again & kept for Use

Now in order to Coppell well

Note that you bee Sure your Coppell be thorowly well redd hott before you Carry any Mettall upon it or else ye moisture that is in itt Still is apt to make it Spatter & jump Note & that you may not Coole your Coppell putt your Mettall upon it by Severall Turnes in pieces or parcells for these following Observations are to be minded in Testing the Cone that you be Sure the Cupell be thorowly heated redd hot before you carry any Mettle upon it for Fear any Humidity yett behind Should cause it co Spatter therefore to prevent or to foresee [p.12] this we Use allways to putt a little bitt of lead upon it first to See & to try how it drives

The other thing to be observ'd is that when now ye Cupell is in it's just right fitt heat that you Cupell it (that you drive it) of Coole only to bring it hotter at the latter end or else it Causes & Settles hills or circkells round the matter upon the Test which is called frost or it is frozen & is a Signe that it is or will turne into lytharidge So that tho you give the Fire as Strong again Yett it will not flow well (melt well) again & ye Inconveniency then is that by this force of the fire it will happen to you that the lead & Silver goes then with through the Test & there is then So much time lost that you reduce your Test again & to begin again anew butt

Note here a remedy When through your Neglect you have lett it come to Such hills or Circkells or Lytharidge that yett You may bring it Some times to right again by carying of Some thing more lead upon itt for that brings it again into a thin Flux that is to Say if your Cupell be bigg enough to Soak in (or draw in) all the lead that was thus Superfluosly carried upon the Test for what lead is Superflously carried upon ye Test over & above what ye Test Can drink in must of Necessity goe thro the Test. Therefore you have well to observe that you give a Test no more Mettall then it can drink up, butt before you carry more lead upon it try it First this way as soon as you See a ring (as the Signe of going too Cool & of turneing into Lytharidge) You remedy it [p.13] Sometimes again only by laying a Coppell of redd hott Cales upon it and a Coppell before the Muffell or make the Fire any way else become Stronger again & you will bring it to it's first Condition if not you Can but reduce it then

Note that those that Cuppell in great quantities (Such as the Refiners) they make the Lytharidge plentifully in order thereunto they Scratch a little hole into ye brim of the Test but doe Scratch it no deeper then the Surface of the Mettle now as the Lytharidge Swims like Oile upon the Test the Wind of the bellows blows towards the hole & there it runs out & as the Mettle becomes lower in coppeling -- you Scratch also the hole lower to that is to Say allways even with the Surface of the Mettall.

Some Additionall Observations For Saveing When One's hand is in in Mettallurgicall Experiments

Note that you doe not Fling away old Tests nor old Crucibles that have Served For Metallick Experiments First you may Save all the Salts that did Soak into them by beating them to powder & pouring hott water upon them to extract all the Salts & those Salts afterwards to be boiled away to dryness, which may Serve again For the Same purpose as before

Secondly what Atoms of Silver are Scatter'd up and down the pores of the Crucible you Fetch out [p.14] afterwards vizt being powdered First very Small you putt them into a wooden Traff or Dish or Mill to wash away all light earthly Stoney Atoms & the metallick part & so likewise all Sweeping may be Saved, Stamp'd & wash'd and likewise all old Tests to Which you had twice as much lead & a little Salt Peter & Some common Salt a top of that & bring it to a good Flux or Fusion in your melting Fournace then pore it out into a Cone & there does Settell a Regulus at bottom of the Crucibelle like unto a ruff glassey Substance Which you powder & mix with it about ye 8th or 10th part of limat-Martis (fileings of iron and Flux it down again & your Reguly is then finer and the Scories are now light & have lost their Shining because the Reguline part is now better precipitated out of itt by the Mars which has imbibed the Sulphurs that did keep it in the Forme of a glassy Substance which regul now may be coppell'd (Tested) to see what it holds so that every thing & Sweepings may be turn'd into Use instead of Flinging it away.

Butt Note if you have a great quantitye of Tests then it would be too tedious to melt them in Crucible's (like your Small Tryalls) but you must apply your Self then to ye large reduceing Fournace (which in German Tongue is called Stich Fournace) as you have it in the next paper's which is done by Bedds of Chaircoales & by bedds of the broaken Tests, (according to ye description in the Next papers) and that is term'd or Stiled [p.15] Stratum super Stratum which wee Signifye thus by these 3 following letters S.S.S.

Note the Second method of reduceing old Tests that are made of Wood Ashes is that you powder them Small that you wash them in a Woodern Traff or dish for thus you wash all light Atoms away & the heavy vit the Metallick part remains then you dry that & mix to it 3 parts of pott Ashes and Melt them down & that makes the Regulus Sinck of which you may cupill (Test) a bitt to see if it holds Sylver or noe if not you Can butt Use thiss lead again for other imbibitions instead of comen lead but if of them you have a great quantity too then pass them likewise thro your Stich fournace with S.S.S (Stratum Super Stratum) that is by turnes Beds of Chaircoal and by bedds of Tests then Chaircoale again & Tests again & So forth.

[p.16] An Account or Essayes upon Copper Oar both in great & Small

Take a certain quantity of Copper Oar vizt half a hundred or a hundred beat it to a fine powder then draw it to a Slich (as we terme it in German Tongue) that is to Say putt it into a wooden traff & with water wash it & by decantation lett the light Stoney Torristricis part floath or wash away & only the metallick part to remaine & thus you may See what quantity of the metallick Coppery part remaines & that is what we call Slich and this Slich now you dry & weight it & thus you know then how much a hundred of Oar yeilds Slich

Note now to know how much mettall this Slich may hold to the hundred you take an Ounce or a pound or a Small Cent, putt it into a dry test & put that into your Essey Fournace under a Shuffell but just into ye Mouth only at First, then further & further into the Muffell, that you may warme & heat your Oar by decrees till it comes to melt at last & to be of a dark brown redd hott, but keep it from melting as long as you can & Stir it about with an Iron hooke that it may not run presently in Lumpes & that chases away & Free's the Oar from it's Superfluous Sulphur, then you may putt it further into ye Muffell to stand Hotter till it's Sulphur be gone & the Oar now become of a brown redd hot condition

Note take of this powder one part & of the usuall black flux 3 parts, bring it to a good Fusion in a Crucibell in your melting Furnace & give it time to Settle & there will be a Regulus which is your Copper but for ye exactness [p. 17] Of your Essay.Remark or take notice here that in Case ye flux Seems to disappear as if it was Swallowed up into ye Oar or as if it was gone through the Crucible by which meanes the Oar would remaine dry in the Crucible (which often happens by hard infusebell Oares) then you add in that Case still a little Salt of Tarter with a little Sell vitri (Glass Gall Sandiver) either allone or both & that does render ye Flux thin again which was to dry before & that does gather your Corne neater & cleaner togather when now your Crucibles has thus Flux't well for half an hour together like wax, lift ye Crucible out of the Fire & knock a little upon it with your pincers or Hammer to make the metall Sinck & So Shall you See what Copper the Oar did hold

Note but in case this Corne or Regulus is Still brickell under ye hammer it is plaine, that it is not brought yett to a good Copper (called in German jaht Copper) then putt it into a dish called a dry Test & lett it flux again with a little Borrax & Salt under your Muffell or in a Crucibell in your melting Fournace and that Scorifyes or purifies it & these two Salts take in the impurity of the Copper & you will have a purer Corn then before which you easily know or See by that it blicks & presents all Sorts of Collours as it Stands in Flux & looks then of a good redd & Soft like other Copper

Item you may likewise dry it this way. Take instead of the Salts a little Lytharidge or granulated lead & a little Borrax and let it Scorifye in a dry Test & it purifies or Soften's ye Copper that it will extend under the Hammer So that those are the Tryalls upon Copper Oar that are pure [p.18] and that are to be much dispersed & Scattered amongst abundance of Stone & earth of which the oar is filled & composed Which by these meanes are brought into a narrow Compass which you now weigh exactly in your Fine Essay Scales how much Copper a Cent of Slich holds from which you can make your reckoning From the Small Cent to the great Cent weight

Note but if you have a pure or finer Copper oar that looks yellow & greenish or Yellow & blewish as Some does like unto a peacock Tale it is not necessary that you draw that to a Slich (vizt by washing & decantations as is Said) but powder it & roast it only & so proceed presently with the Salts by Fusion as before Said Or take Copper Oar test it under a Muffell till it does melt no more, then take 2 parts of the Flux (vizt tarter & nitre) or rather 3 parts, bring it to Fusion & you will have a whiteish matter, beat that to powder & calcine it again (I mean toast it again) then Flux it down again with double the quantitye of Flux Sometimes it need to be done 5 or 6 times before it comes to be right Copper

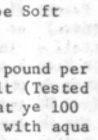
Or thus (if a copper Oar be of fine Yellow) take a Cent of the oar powder it Small, then rubb it a little upon ye porphyre Stone then toast or roast it then take 3 parts that is 3 Cents of black Flux & the 4th part of Lytharidge & Some Com̃on Salt atopp of it, the thickness of a quill, Flux it down, then break the Crucible and take out your Corne of Copper & purify it from it Scorys under a Muffell in a dry Test & a little Borrax & blow to it & the Corn purifies itself quench it in Urin & it becomes of a fine redd & a hundred of this Oar did hold 8 pound

[p.19] Note upon Some Copper Oar lett your Flux be Soft vizt of 3 parts of Tartar & one of Nitre

Note this Corn of the Foregoing oar that holds 8 pound per cent I did try whether it holds Silver and Cupell'd it (Tested it) with 16 part that is 16 Cent of lead & I found that ye 100 did hold 12 ounces of Sylver then I did Seperate this with aqua Fortis & it did hold gould

Note when I have Such a Small tryall of gold, to know whether it be certainly gold I do thus vizt as Soon as it is desolved by the aqua fortis & the aqua fortis pour'd of from the Calx and the Calx wash'd once or twice with fair water I pour ye Calx upon a Test (Cupell) & that Soakes presently in the water then I sett the Cupell a little under a Muffell to gett it just dry then with a pen knife take of this black Calx & lay it upon a white paper & with the point of your pen knife Spread it & rubb it & you Will See presently how Yellow it is or take it between your two Nailes of your Finger & rubb it & you will See the Same

Note this instrument or pott with it's cover [Fig.4] vizt an earthen Vessell made of Crucibell Earth is in those tryalls very Usefull instead of a Crucibell if you can have them For thereby because of the point they have your Corne (ye Mettall) drawes better to a Centre for you will find that the Corne lies bare & it is but knocking of the bottom (the foot) & your Corne lies bare but observe that you do not fill those potts above half full for it is apt to run over and that would be then a false Tryall



[Fig.4]

[p.20] How to Treat Copper Oar in great

Note it is done with a great Furnace called in German Tongue the Stich fournace as will follow next wherein you can melt down a great many hundred weights at once

The Oar for this purpose must be broke Small the bigness of Wallnuts in order thereunto you must first make or compound the following Flux or Scory

vizt in order to which you must have a certaine Clayish loomy Substance or Earth which nature has provided allready as it's remedy & is generally found at ye Same time near or not Far of From ye Oar again you must have also a certaine matter call'd Copper Scorie that is to Say Scory's that have Serv'd allready before now for the Same Use or else you take instead of that Iron Scorys which must be broak Small & these you mix with the Foregoing Lettoon (so it is nominated) of both each equall parts & these you putt into your Stich Fournace, bed by bed, that is to Say, a bedd of Chaircoal first and then of the mixture (vizt the Lettoone & Iron Scory's) namely first a good traff full of Chaircoal & blowing the fire after that upon it a traff full of the mixture then coales again, then the mixture, then Coales again & so forth dureing which time you have one or two pair of Bellows blowing into the Furnace a Cross the matter with great Violence that the matters permiscuously may come to flow (to meet) perfectly well, then you pierce your fournace to lett the melted matter run out into the forehole or foreheart as it is called & this is your flux or remedy [p.21] for your Copper Oar that is to Say When you can have no other Copper Scory's & these Scory's or flux when well made must look like a black Glassy Substance & if So are then counted to be purified from the dross of the Iron & is now become a fitt flux for your Copper Oar

Now the flux for the work being done you must clean your Stich Furnace (your piercing Fournace being So called because of piercing it or give it a Stich) again and make therein a new bottom (which is called in German Tongue A gestube that is to Say a bedd or boddom or to Speake more plaine the lining the bottom of the fournace with Chaircoal dust mix't together with Some loome & water vizt 3 parts of loome to one of Dust to be made into a Past or Lute with water then it must be Stamp'd hard & firme with a Stamper which is warm'd before hand for that purpose & this Gestube (this lining) must cover the whole boddam of the furnace vizt it must reach from ye place or hole where ye bellowes blow in to ye front or foremast wall then being Stamp'd thus firme like a threshing Floar you must cutt into it a Concave (a Holloness) like a Gutter downwards begining from the Bellows holes downwards to ye front, that all the Mettall may be able to run downwards to ye place where you pierce the furnace

Now take about 4 hundred great weight of ye Copper oar broak into Small bitts the biggness of Wallnuts & as much of the prescribed prepared flux & likewise of the quick lime Stones that is to Say the dry raw Stones only before they are burn'd into lime of each equall quantities [p.22] These Ingredients you mix well togather in Some pure corner or other or upon Some place that is contriv'd with boards on purpose for this Use, as you will See below & now ye Matters are ready for your Work or fusion these now are putt into your furnace S.S.S that is to Say, bed upon bed, first a traff full of Charcoal then blow to it to light it then the Matter upon that & then Charcoal again then of the mixture again & So forth then by great force of blowing into it a cross the Matter with your great Bellows the matter must be brought to a perfect thin and flowing Condition or flux that all things bee perfectly melted then you peirce the Fournace at ye lower end with a Spike (look amongst the Tools) to lett out the mettle into the forehole or foreheart as it is call'd (as you See by the draught of the Furnace) and there comes mettall & Scorie alltogether, but the Mettall as the heavy part Sinks but the quick lime Stone (the Calx Stone) as the lightest & which has Soak'd up or imbib'd the unpure Sulphurs of the Oar is the uppermost & these because the melted Matter in the foreheart becomes now Somewhat hard or toff by the Coolness of the Air & formes Soon hard Cake upon ye topp or surface of the mettall the thickness may be of an Inch which Cake you lift of from a topp the mettall by an iron two Spik'd fork as you find amongst the tooles then the Coolness of the air makes it presently gett a Second hard Surface and you may lift of a second Cake nay a third & fourth Cake and which Shows it Self when it is enough for the lower most part is the Copper but itt has or containes [p.23] Still Something of impurity & hardness of which more by & by

Note it is convenient that you lift the Copper (ye bottom) of two Cake the thickness of an Inch by degrees as ye coolness of the Air formes the Surface into a Cake. For the Copper may then the better be broak into bits with a great Hammer then if you Should lett it congeale all into one great Lump for there then would be no handling or dealing with it then being So bigg therefore it must be broake into bitts as Small as a the bigness of an Egg for it may then be the better Spread upon the Place where it is afterwards to roast which it must

Remarks

Note the reason why you add here the Calx Stone (the quiklime Stone) is, that because he being of a porou's drye Alkaline nature, all the wild Sulphurs or Acidity of the oar mortifye themselves & their points upon it to death and the Sulphurs are Suck'd up, Swallowed up & imbibed into it and Consequently must lett goe the Copper, for otherwise if the Sulphurs or their acid point had nothing to Spend themselves upon, they would Still keep the mettall Solubell or dispersed in the Oar and not Separate, but would come out of the furnace inseparable and remaine only a mix't mass which we call in German tongue (eine Speise) in English a meal, a mass or imperfect mettall that is neither Copper nor Iron for as long as it is only eine Speise (meal mass) &c it is then only a brikle mettall that Suffers no hammer and cannot be made use of except [p.24] only for Mortall pieces, Cannon, or Bellmettle & you will then consequently have butt few Scorys to lift of or to take of from ye melted mettall as it ought because the Sulphur as above Said is not Sufficiently Separated or imbib'd & So keeps the mettall up Still desolv'd

Note you may pass the last Cakes a second time through the Stich fournace & tap it of & take of Scory's in Cakes as before So Shall ye bring the mettall Still in a narrower compass yet because it is by these meanes freed yet more from its Scory's

Note now you have done with your Copper thus far make a bedd or lay of wood (billetts) as bigg as it needs to roast it the wood must not be too Arid (dry) but yett Something greenish that it may have yet Some moisture for if too dry, it must be laid Soaking into the water to lett it Soak full then lay down Some wood, Some Sticks (billetts) to make or to forme 4 Sides (Side places) one near an other & then other peices a Cross upon that but above (atopp) of that lay dry wood & then chair coal & upon that Spread your melted work (your Cakes) and make a fire & the copper will be roasted or toasted or burned gradually of this way for it will make the Copper flow out of the Cakes like hair as if the Cake was grown thus hairy and very Curious it is to observe & to See it thus how wonderfully & Strangely the Copper is brought to perfection

When it is now thus roasted, take this roasted Copper and melt or pass it again thro the Stich Furnace as before but without addition & lift the Scory's of out again as before with your pitchfork & you will have allready very fine Copper called Kings' Copper or black Copper

[p.25] Butt note to finish it now or to bring it now all togather good fine Copper, make a hearth before the blast with a good grtubr (gestube) that is to Say the hearth lined with a Lute of loome & charcoal dust and beat firme like a Test & a Cavity cutt into the midst of the Test as you use to Tests which you burne out very well by lying charcole unto it that it may be well dry from all it's moisture Now take great Chaircole that are not well burn'd out but that may give yet Some Flame and make fire upon the Hearth, upon that lay your kings Copper (so called) & Coales again and blow to it very well till you melt the Copper and that it drives (Coppells) upon ye hearth and it will Still present upon it like Eyes as if there was Still Some flux (fluxing Salt) with it w:ch draw of with a rake and the Copper will drive bravely and pure and represent all manner of Collours as a rainbow and blick and then you may account it good finished Copper to work Smooth under the Hammer

Further Remarks

Note why Swedish Copper is finer then English, is that they toast it 7 times before it is melted down which is done S.S.S. (Stratum super Stratum Bed upon Bed) with wood and pieces of Oars between 3 walls upon the bare ground without a grate before the Copper is well opened, this doing of it 7 times, let it every time grow cold again & it is better then to keep it in one continued Fire tho you Should allow the Same Number of houres [p. 26] because to continue it in the fire fixes the Sulphur into ye Oar & there it Shelters -- very obstinately, whereas at 7 different times Toasting it is better to draw or drive the Sulphur away, afterwards it is melted twice to make it fine, but the english Oar is not calcin'd half so long because it would make english Copper else come too dear if they Should make it So fine

Note the flux for the Copper oar we have here mentioned So oft, is prepared there, where we find no Copper nor can have none So is this flux made instead of the Copper Scory's

Note every Stich fournace full has or yeilds his Scoryes & these Scoryes may Serve very well 3 or 4 times for remedy or Addition before they are flung away

Note the tearmes of these 2 German Words of Seigern & Sicheren, in the Copper processes are these that the word Sichern is when I have a Barr of Copper, which is mixt with lead and that I bring the lead away from it, then I lay the barrs over some fire to roast or to toast, that is to make them become of a brown redd or allmost, but not to melt and the lead forces it way thro the Copper & leaves the Copper very porous & perforated and that is called Sichern but ye Word Seigern is to wash away the earthly part of oar when it is in powder, to free ye Earthly part away from the [p.27] metallick part & to bring the Mettall thus into a narrower Compass

Note Lettoon as is mentioned in the begining is a fatt Yellow loome or earth which is called ZnSlay Znslag [Zuslag] in german Tongue (additions english) which is used for ye Copper oar & is its remedy which also are generally found round the hills where the oar is digg'd and which is to be known by that, when you roast, Toast this earth this Lettoone, you will See it turne reddish and that is the best and fittest for Such oares

Note that what we call Scory's know that ye Scory's are nothing else as additions ZnSlag Zuslage which are added and used for your flux to bring the Oares in thin Fusion, by which meanes the mettall is the better extracted and gathered together and precipitates it Self down wards and the fluxes or additions remaine Swimming atopp with the impure part the oar was charged with, So that ye Flux ZnSlay or addition is then hard or tuff in somuch that it may be gathered off or taken of very comodiously with a pitchfork from of the melted oar while it is yett warme but is as brickle as glass when it is coal'd and that is called Scoryes. butt

Note that those Scories that are yett pretty glassy and black is a Signe that they are yett very fusible and Consequently yett very fitt & Serviceable to be added to other new oar for they are of that Use that they will bring the Oar the Sooner & faster in flux

[p.28] Note the sooner & faster the Oar is brought into Flux the richer & more mettall you gett for it is not good but bad when it lyes So long in the fire toff and Clammy and Sticks and adheres only every where about the Sides of the Furnace therefore it is better that it be brought thin in flux very Soon for it is with this as with a Crucibell when a mettall is not well brought into flux in a Crucibell it hangs about it & Sticks to it and Setles noe resident or Regulus well and there is Dammage then & thus it is the Same with great melting

Note the place where you mix the Oar and Scory's at first togeather is either a neat clean Corner that you Sweep & is kept apurpose for that Use or else a Square (a four Square) boarded great traff with boards on each Side of a foot high but before (the heither end to be free for your Shuffell and arms to mix the oar

Note the Instrument wherewith you Stamp the hearth or bottom is a great Stamp or like unto a pestell which is of Iron and a long Strong handle or pole to it of 5 or 6 foot long & the Stamper (vizt ye lower end) must be warm'd when you are going to Stamp & to beat your hearth firme

Note to try a Copper whether it holds gold take an ounce of the Copper you have made and one pound of lead which is 16 parts to one melt them both together in a Crucibell then granulate it that is pour it into water when it is melted while an other moves that water quick about with a Stick then [p.29] dissolve it in aqua fortis & if there be gold it will lay at the bottom in the forme of a black powder like the Sollution of Silver but as the aqua fortis may either be too Strong or too weak for this Use the Surest & best Tryall is to putt it upon a Test & to cuppell it of & what Silver or gold there is in it will remain upon ye Test

Note here for conclusion that for knowing what quantity Such or Such copper oar does hold a Short & exact way is to calcine ye Oar then to powder it, then to extract a blew Tincture with Spiritt of wine [i.e. urine] or Salt armoniac & that Severall times till it acquire no more blewness, these Extractions or Tinctures now putt into a glass retort or glass body to destill of the urinous Spiritts till to dryness & that Spiritt Serves again at other times & the remaineings in the retort putt into a Crucible to melt it down and there is your Copper

[p.30] The Description of the Stich Furnace
So called in German Tongue for melting of Oars
in Great & which is managed by 2 large
Bellows to blow into it

The forme of which you here have vizt behind & the two Sides of the furnace namely the right & the left Side to be 6 foot high & 3 foot in breadth but before (namely the forewall of the furnace) Number A [see Fig.5] only 4 foot high the furnace is not alltogether 4 Square but hee is in breadth 3 foot namely in the front A & 2 foot the other way namely from the forewall to the hind most wall

Note this furnace must be build so as to Stand one foot under ground & that Same part under ground must be hollow that is vaulted (according to the reason behind in the remarks) and this Holloness this Vault must have a Tube (a pipe an opening) Numb B and this Tube must come up out of the ground abt 5 or 6 Inches above ye Ground according to the reasons in the remarkes) and the Surface or uppermost part of this Vault must come even with ye Surface of the Earth, but if you do not vault your Furnace with brickworth you cover it only with an Iron plate upon that now you make your hearth which is called in German tongue fingrtübr. that is to say a bottom or bedd or a lineing of the furnace made with Cole dost and loome and a little water beaten or Stampt [p.31] firme with a Stamping Tool

Note but wee will Spare the building of this hearth or lining of the boddom to ye last & go on first with the building of the furnace therefore go on with the building of your 4 Walls or the 4 Sides of the furnace a top of this Vault or plate 2 foot higher a top of which 2 foot you have a hole in the hindmost wall for this hole is designed for the forme Nr.C that receives the Nose of the 2 bellowes then go on Still 2 foot higher with the walls & that is now 4 foot high

Note a top of this 4 foot now you must build ye hind part of the furnace & the 2 Sides of the furnace letter D Still 2 foot higher to make out the forementioned 6 foot of the furnace, but before the furnace remaines only 4 foot high but these 2 foot brickwork must Spread like a funnell that the furnace may be about a foot broader a top then below (according to letter (D) for the reasons mentioned in the remarkes namely for the easier receiveing the Oar you throw in & to Slide down into the furnace

Note what is to be minded in the front or foremost wall letter A is this that yo have a hole in the wall in the forme or Circle of half a Moon letter E and that about a foot high from the Surface of the Earth but yett you wall it or Shutt it up too for this hole Letter E Serves only for that that upon Occation you may creep here easily out & into ye furnace to clean [p.32] or to mend the furnace & to lay or place the bedd or boddom (called Gestube) for thus you do not Spoile the furnace but you open only this hole this Circle which you wall up again as Soon as you have done your work within upon this Circle you wall up your brickworth 2 foot higher & that makes now out the height of 4 foot in the front letter A

Note that below this Circle or front wall letter F (vizt without furnace at ye place where the furnace must be usually pearced you build a circle (Circuitt) half moon like the breadth of the fournace the Center of this Circle till to ye furnace may be about 4 foot wide and a foot high & this Circle this ring this half moon (& which is called a foreheard or Crucibell) is build upon ye Surface of the earth & is made or walled up with brickwork or you cause instead of that a Strong Iron ring to be made that is as deep & as bigg as the brickwork and this as allready Said is called the forehearth or receptacle or Crucibell for to receive the melted matter as you peirce the furnace

Note now to this forehearth or receptable letter F you have at both Sides below a hole abt 4 Inches Square & there you Cutt a hole or Cavity letter G in the earth in the ground the biggness of a half Canon ball & thus your furnace is finished and ready for Use

Now, there remaines to be minded within the furnace ye boddom or harth

Note this harth must be beaten firme with letter H and that must be made Slopeing vizt high [p.33] behind & low before) that ye melted mettle may run easy in ye forme of a point towards the pierceing hole to be tapp'd & this grtubr or bottom is made of 2 parts burnd loome & one part Chaircole dust mix't & moisten'd with water (as we doe the Tests or Coppells) that it may be butt just clammy & to ball a little you must Sprinkle the fournace first a little with water to wett it then you lay on your moisted loome & charcole dust to it you lay powder enough in that it reaches to ye forme letter C then you Stamp it bravely firme with letter H as firme as a thresing place the Stamper must be made warme when you have now Stamp't it bravely then cutt your Cavity with a Spur Iron letter H as is fitt & convenient that is to Say Cutt Slopeing downwards for ye Mettle to run downwards to ye Stich hole or pierceing hole

Item the Same you Serve yr forehearth or receptacle letter F for you fill that likewise with your Gestubu (vizt Charcole dust & loome) & beat & powder it hard & cutt there also a Cavity with the Spur iron as we Use to cutt ye Tests hollow

Note while you do this in order to make your gestube (your bedd) right & orderly you take a board cutt like unto a point (pin or piramade) w:ch you push into ye pierceing hole (that the Stich hole) the pierceing hole may not be fill'd up but to remaine open this board or pin you daub with tallow to be greasy [p.34] that it may the easier be pull'd away again as Soon as ye bedd or Gestube is beaten firme & which easily come out because it is greasy

Item the Same you do with ye hole in ye forehearth letter F where you must likewise push in Such a pointed board or pin dureing the time you Stamp that the hole may keep open then you pull away the pin & the whole is open

Note this is done make the forme behind ye furnace letter C fast & lett ye Forme goe into ye furnace abt an Inch & a half or 2 Inches take notice that ye End of it bee bending Somewhat downwards as it were pointing towards ye Stich hole (pierceing hole) towards ye hearth then fix therein the Nose of your two bellows

Note to doe things well you must try ye bellows whether the blast blowes directly towards the hearth which yo doe or try with a white board vizt greated & Cole dust Spread upon it or if the board be black chalk upon it & thus you easily See how well the blast fetches it of

Note that for Tryall of this One end of this board be plac'd presently under the Nose of the forme and the other end of the board into ye Stich hole (pierceing hole) till to ye hearth or receptacle then fasten your forme (make it fast) and your furnace is in a full Condition ready for Use

[p.35] Note these two bellows are placed So into the forme that they may play or blow a cross way into the fournace but note before you Use the furnace that you heat & dry him very well first thoroughly with Chaircole first So Shall you See how ye damp moisture or vapor comes out a pace out of the Tube from the vault B for without this Vault (or Anzug as the Germans call it) the ground or Earth would furnish allways new moisture for which reason it has need of this Anzug or Vault

Remarks

Note it is necessary that this furnace be placed or built where he may Stand dry & free from the Injuries of raine and under a Covenient Spacious Chimney for ye fumes to ascend & that has Sufficient elbow roome to Stir about

Secondly the Vault or Cavity under the furnace togather with it's pipe or Tube B is therefore that ye humidity which by reason of the Fire & the heat is attracted from ye Earth may not damage the Furnace but that this humidity may dissipate it Self by it & this Vault or Cavity is called in German Tongue an Anzug or english an Attraction

Note this Tube B must rise Some 5 or 6 Inches above ye Ground for that reason that not any rubbidge may fall into it easily but that it may bee easily covered over when the furnace is not at work [p. 36] Item you make this Tube B to come of Some distance from the furnace that it may not be in the Way & the Orifice of this Tube be of Some 3 or 4 Inches Diamettre

Note the forme C wch We call a forme is a Strong iron Tubb at least an Inch thick and this Tube must be taper downwards the end of which to be about 2 Inches Diamettre & in this forme C the noses of the 2 bellows come to lodge thro which to blow into the furnace

Note that ye 3 Sides D of the Upper part of the furnace (vizt the lefft & right Sides & the hindmost part) according to ye Draught are therefore made wider atop for the conveniencye to come at ye furnace ye better of throwing in easily traffs full of mettall

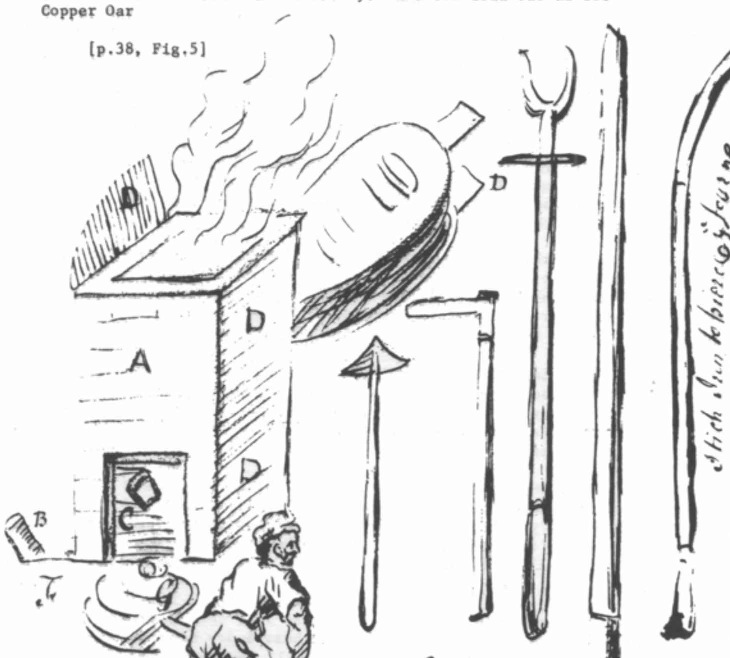
Note the 3 Sides D of the upper part of ye furnace (vizt the left & right Side & ye hindermost part) acording to the draught are made wider a top for the conveniencye of throwing ye Oar in ye better as it were in the manner of a funnell that is wide a topp & narrow below therefore the fore most wall is lower then ye rest for the forewall is but of 4 foot high when the other 3 are near 6 foot high

Note the bigness of the Space within the furnace is 3 foot wide one way namely the front & the other way that is the Side walls from the front towards the back part one foot & a half but the furnace must be lined & then he is not above 2 foot & a half one way and not much above one foot the other way

[p.37] Note but this Lineing of the furnace is only done below I mean at ye lower part of the furnace where the greatest heat is, namely all that part that is below the forme but ye Upper part remaines wide as it is for he is not to be lined higher then the forme

Note One might presently at first make the furnace with brickwork to that dimention without narrawing it with lineing it but the lineing of the furnace is better for that way furnace remaines allways whole but likewise has this Conveniency that ye Matters do never Stick So fast to the lineing as it would to ye bricks & this furnace can likewise be used ye Same for lead Oar as for Copper Oar

[p.38, Fig.5]



[p.39] Essayes upon Lead & Tin Oar
by the Following Flux
which flux Serves also for any other Oar

Take 2 parts of Tartar & 1 part of Nitre powder & mix them both well together then put a Spoonfull of it into a morter or earthen pipken (which you warme before hand) touch it with a life Charcole or redd hott Iron & it will take fire imediately which is called Detonation then carry the rest of the powder upon it Spoonfull by Spoonfull till all is detonated or blased away in this manner which powder you keep Stopt up in a bottle ready by you to keep it from growing moist of the aire & this is called ye Black flux

Take of this flux 2 Cent to one of any Oar & putt atopp of both a little comon Salt (that has been melted in a Crucible before hand) & give this a good fusion in your wind furnace or before a pair of bellows till the fusion be as thin as water then liff't the Crucibell out of the fire & lett it grow Cold knock of the Scories & at ye bottom is ye product of your Oar

upon lead Oar

Note take one Cent of the oar powder it Small then take 2 Cent of the black flux mix both well together but mix likewise with it a little fileings of Iron about ye 4 or 8th part then put this into a German Crucible & a little Sat fusum a top of it to cover the Oar about the thickness of a Straw & cover the Crucibell with a piece of tile to keep out the Coales & lett it melt by degrees & when [p.40] Itt is well melted the Mettall or regulus Settles its Self to ye bottom of the Crucibell then lift it out of the fire & lett it grow cold of it Self

Note as there is different Sort of lead oars so may it be tried different wayes therefore for a Second way take lead Oar nitre & Tarter of each equall parts putt it into German Crucible & bring it to a good flux or fusion in your wind furnace or before the blast then lift the Crucibell out of the fire & lett it grow Cold then break your Crucibell & the lead or regulus of the Oar ye will have at ye bottom

Again Note that Some Sort of Oar must first be roasted (tosted) as We call it of which you have had an Account allready in the preceeding papers namely, that it is done under a muffell in your Essey Fournace that is to put the Oar finely powdered into a dry Test (Dish) & Shove it under ye Muffell first in a little way to warme & to heat it by decrees then a little further till at last it becomes to be of a browne redd hott heat but it must be Stor'd with an Iron Hook all the time to burne of or to chase away Some wild Sulphurs which do hold the Mettall bound fast the putting the oar in by degrees is only to hinder the oar from melting too Soon that the Sulphurs may depart the easier Now when it has been thus roasted take of it one part or one Ounce & 3 parts or 3 Ounces of the flux vizt tartar & nitre & flux it down before the bellows or Wind furnace [p.41] and you will See what you have Item or take 4 parts of lead Oar powder it Small and mix with it one part of fileings of Iron & give it a good fusion & you will Soon See ye Regulus precipitated to ye bottom of the Crucibell for ye Iron has here imbib'd (Suck't up) the Wild Sulphers being Alkalcons & the Regulus being freed thereof Sinks then to ye bottom by its own gravity & you See what you have

Again or try your lead Oar thus take of the lead Oar 4 Ounces of Tarter & nitre & comon Salt of each 4 Ounces (the Salt must have first been dryed, powdered and Siffted else it will jump decrepitate) or else must be flux't down in a Crucibell to make it a Sat fusum & mix with it 2 Ounces of fileings of Iron being well mix't togather flux it down as is mentioned above allready before & you will See the product of your lead

Again Sometimes you do it this way vizt When you have beat ye Oar into Small powder that is to Say if it be a dry poor oar take of that & of lytharidge of each equall parts lett it come to a good flux putt a topp of it a little putt ashes (called Cineres clave Clatae) [cineres clavellati] & a little Kitchen Salt or rather Sal fusum for ye Salt hinders it from riseing in the Crucibell which otherwise is apt to run over whilst it is in flux & there is your Regulus at ye bottom but ye Lytharidge being lead it self & reduces by this meanes again into lead So that you can make no Calculation what quantity of Mettle your poor oar did yeild therefore you must reduce the Same quantity of Lytharidge by its Self [p. 42] in the Same manner (that is with the Same Salts and fileings) & weigh what quantity of lead it holds & So you abstract that quantity to make your right Calculation So that you have here a full Account by different mixtures how to try all manner & Sorts of lead Oar

Item now for a Tryall of Tin Oar

Take your Tin oar beat it to a fine powder wash away ye earthy Stony part with water in a Wooden traff according to ye Method allready hinted in the foregoing papers (which is called Sichern in German Tongue) for washing or Sichering it thus, the Stony part being light Swimes & washes away butt the metallick remaines being heavy then dry this metallick part & weigh of one ounce & of the black flux (vizt tarter & nitre) and borrax of each one Ounce Sometimes 2 ounces according as the Oare is rich or poor & flux it down in a german Crucible just as you did with the lead & you will See what product you have Note but the black flux for this purpose you lett here be made of equall parts of Tartar & nitre & then the flux becomes a little Sharper for in Some Oars it may be too Sharpe or corroding & in that case you take 2 parts of tartar to one of Nitre or if So be you will make it milder yett 3 parts to one & thus you may try any Sort of Tin oar without any other Mixture then this

[p.43] Remarks upon lead Oar

Note what is meant by roasting or toasting of Oar is (tho we have mentioned that allready before now Yett to make this Account of lead Oar intire -- without lookeing first to other papers take the Account again) that being rub'd fine into powder & being putt into your Essay fournace upon a dry Test under your Muffell You give it at first only So much fire or heat as to make it become to fume (to Smoak) by Sturring it of't about with an Iron hook till at last it becomes to be of a browne red heat in the fire which you continue as long as you perceive any fumes & this chasses away all the loose Supefluous Sulphurs (which We call Wild Sulphurs) of which it must be cured before it yeilds to you its mettall Note a Slow fire is made upon this Score that it may not bring the powder presently to a fusion for then the Sulphurs keep the mettall close united & will not lett them goe

Note ye Addition of fileings of Iron is for ye Same reason added to ye Oar to imbibe & to Suck up ye Wild Sulphurs that the Sulphurs may lett goe their hold for the acid points of the Sulphurs are nipt & broak upon ye Iron as being of a very porous Alkaline nature to which the Acid of the Sulphurs adhere & leaves then it's mettall in course and the Sulphurs are Scorified in the Iron & Swim a topp.

[p.44]

Note The com̃on Salt which you make here Use of in your fusions must have been flux't that is flowed or melted in a Crucibell then when cold, powdered & kept ready by you for Use in a bottle Stop't as you doe ye black flux to keep it free from the moisture of the Air for if you was to use Sea Salt or kitchen Salt as it is it is apt to fly to jumpe, to decrepitate because of the moisture or water that is lodg'd in it therefore it must be gott thence & that you doe by fusion tho the bare drying & powdering it Small will doe to because the Crystall being broak the water or moisture finds no resistance but exhales away without jumping or decrepitation

Note if you will know whether your lead holds Sylver, treat it in the following mañer then Coppell it vizt take lead Oar one part pot ashes 2 parts Com̃on Salt one part & one part limatura martis mix it and flux it knock of the Scory's then putt into a Test under your Muffell & Copple it & you will See what it leaves

Note take Notice if So bee you employ Fluxing Salts enough in reducing your lead Oar you need no roasting of the oar at all for roasting is only done to free the Oar from the biggest and most loose Superfluous part of it's Antimoniall Sulphurs but the Iron is here an excellent remedy to imbibe these antimoniall Sulphurs and to Scorifye them that is to make them goe into ye Scory's which then because of their lightness Swim a top in the Crucible and the Mettall Sinks by it's gravity

[p.45] Note this Scorifying of Oares or mettalls is one of the chiefest rules or necessitys in the Essayes of Oares or mettalls and afterwards to reduce them Scory's & then you See what is in itt

Note if you will treat your Oares in great then these Antimoniall Sulphurs (So usuall to Oars) must be imbib'd & imprison'd with the addition of quick lime & Iron Otherwise they will not lett goe their mettalls but makes only a Sort of flux a fusion which is call'd in German tongue eine Speise that is to Say a Meal or in plainer termes a thing that is not yett a mettall for if there was a Separation then there would be Scories & the mettall namely the one a topp & the other below but while both make yett one Corpu's (that is not yett Separated one from an other) it is called Speise or meal in english

Note Iron allone will also Separate the lead from ye Oar by takeing one part of Iron to 4 parts of lead Oar & the Sulphurs lett go their hold & goe into yr Iron with greediness or Eagerness & the lead being freed falls

Note that in the fusion of lead or Tin oar when you lif't the Crucibell out of the fire that you do not quench ye Crucibell in water as usually we doe in hard Oars because it is apt to Spotter now & then but lett it grow Cold of it Self therefore

[p.46] Note Trying the other day a wild Altimoniak Sort of a lead Oar that promised but little by Sight for it look't very cource in its points or flakes or Shining Anghells but I did roast it with about ye 4th part of Calx (quick lime rubb'd very Small & 3 parts of black flux mix't with it & the 8th part of fileings of Iron and a little com̃on Salt a topp of itt & I gott 29 pound of lead out of a 100 by calculation which was very hard this I tried upon Silver (that is I coppell'd it) and I found that a Cent (100) did hold 6 Ounces of Silver that Same I tried upon gold (that is I quarted it by aqua fortis & I found a Shoe of gold So that you must not content your Self by lookes only but to make Essays for everything

Note to make the Vitrum Saturni or glass of lead for Severall Uses is as follows vizt Take white Sand 1 pound & 3 lb Some times 4 pound of red lead (minium) fine powdered Sifted & mix't lett there be Crucibell red hott in your fire first then Carry Some Spoonfull of your mixture into ye Crucibell Spoonfull by Spoonfull by decrees as it melts & there keep it in a thin fusion till you have brought it to a Yellow glass (Vitrum) which you keep allwayes ready by you for Use for it Serves as a water for dry Oars or for reduceing the Calx or Calxes of other mettalls butt.

[p.47]Note that the lead glass made with white pibbell Stones instead of Sand is better (where you work for gold) for they are of themselves allready a little goldish, wherewith Projectors use to cem̃ent your Sulphureous Oars or Calxes (Crocusses) of Iron or aes ustrum (burned Copper with Sulphur) which they suppose to have a Subtile Volatile gold or Silver (that is a tendency to it) which One may doe also for pleasure & it is found by Experience that ye longer a Silver with regulus & Nitrum Saturni & with Mars & Venus is kept in the fire the more there will Separate what is gooldish or Sylverish in itt for by this continued Motion of heat & fireing & length of Time the Sulphurs & Mettalls receive a fine & equall Circulation & Can fix one an other the better to See what it produces if you Work right

Note that to reduce your luna Cornua which is a Calx of Sylver) by glass of lead take two Ounces glass of lead beat it to powder & mix with it an Ounce of your luna Cornua lett it come to melt then putt a little Nitre upon it & when all is well in flux Scatter Some Chaircole dust upon it as long as it has any detonation or flushings then lift your Crucibells out of the fire & you will find at ye bottom your luna Cornua reduced again to Silver for by glass of lead you may reduce any Calx of Mettall as well as all hard [p.48] Stubborne infusible oars that are poor & dry & won't come into flux easily for this is their Vehicule or water to desolve them, Sometimes you take 2 parts to one Sometimes three

Upon Tinn

The way of cupelling Tinn is as follows

Take Antimony & Tin of each 1 pound melt ye Antimony in a Crucibell then put in the Tin by decrees bit by bitt till it has taken it all up & become One Masse or mixture while this is in fusion Stur it about with a dry Stick and not with Iron that there may be no precipitation of the regulus (I mean of the regulin part of Antimony) because we intend to have here only a bare mixture to divide ye Tin Now take 3 pound of lead upon a Test (Cupell) in one of your Cupelling furnaces & when the lead is become hott enough that it drives (Coppells) then throw upon the lead Some of this Mixture & more by degrees & it will Coppell & drive butt if it happens that Some of itt remaines & is yett uncoppeled putt a little Sulphur to it for it is the Sulphur of Antimony that does it & fitts it for to Coppell

Note because Lytharidge does hold no Silver it is allways used instead of lead in tryalls for all lead has a little Sylver more or less therefore if you have Some nice thing to test that you expect Silver [p.49] from, take lead that is reduced out of lytharidge for your Experiment and Not the com̃on lead because many are deceived by it that think to have had Some Sylver out of their preparation when in reallity it came only from the lead for lead generally holds Some, Some more Some less but Lytharidge none

Note here two very good fluxes upon tin vizt take borrax 2 ounces Nitre 4 Ounces & Tartar 4 Ounces mix & powder it

The Second take borrax 2 ounces Nitre 4 Ounces Tartar 6 Ounces & Com̃on Salt four Ounces Mix & powder them & keep them for Use

[p.50] Essayes upon Iron or Iron oar upon Pirithis & Severall other Subjects with various Observations

Note to know if your Oar be Iron oar powder it pritty Small but not alltogether fine for else it Spoiles the Pole then roast it (Calcine it) that is to Say lett it only become well red hott for a while upon a dry Test under your Shuffell in the Essay furnace then you may try it with the loath Stone what Iron it drawes Butt take notice that you lett it grow cold perfectly well or else it Spoiles the loathstone

Note the Second essay or tryall to know what is an Iron Oar or noe is take a little of the Oar, beat it to powder then put it into a Small boldhead called Eggs & pore upon it Aqua fortis or Spiritt of Salt & let it dissolve as long as it will act or worke upon it lett it grow cold of this Solution drop a few dropps upon a Solution of Galls & you will easily See whether it turns black or noe for all Martiall Subjects tends to make a black or Inck To make the Solutions of Galls for it, it is but Scrapeing or cutting a Gall nutt to Small thin bitts & to pour 5 or 6 Ounces of fair water upon it & lett it Stand in a Warme heat for 3 or 4 hours to extract then lett the powders Sink

Note a third Essay to know an Iron oar is, take of it & Calcine it upon a dry Test under ye Muffell in the Essay Fournace to chace away it's Superfluous wide Sulphurs as is used allready in other Essays upon other Subjects in the papers before related of this calcin'd Oar [p.51] take one part add to it 3 parts of the black flux made with Nitre & Tarter or ye fix't Salt of Lime & Salt almoniac which is quick lime & Salt Armoniac equall parts powdered mix't & flux't down in a Crucibell by a quick fusion which you may keep ready by You in a glass Close Stop'd free from ye Moisture of the Air ready for Use with this Salt or the black flux you melt your Iron oar down in a Crucibell Sometimes while it is in flux you putt a little quicklime upon it for this being an Alkalcon's body imbibes (Sucks up) Some of it's Sulphurs & the Iron precipitates better down to ye bottom Sometimes you add a little Antimony to it & that fetches out the Iron the best & gathers it together away from ye Stony part presently but

Note here that if you meet with Iron oar that is rich enough that Same need not be roasted or calcin'd for trying it with loath Stone but only to powder it and to pass your loath stone over it & all what is in it Iron adhere's to ye loath Stone & leaves the Stony part behind brush it of from the loath Stone & pass him over the Iron oar again to fetch out Some more & that So of't till no More adhere's to ye loath Stone Which afterwards you weigh by your Essaye Scales & you easily See what a Cent holds

Item a very good way it is to take the Iron Oar when it is Calcin'd as We have Said & that you have noe loath Stone to putt it into a wooden Traff & to wash it (to Sicher it as the German calls it) that is to Say [p.52] to free the Oar by washing it from the Stony part Which being light easily Swims in the Water but the metallick being the heaviest remaines behind in the traff and being So much freed from the earthy Stony part a lothstone fetches the iron thence ye more prittily & better

Note all Oares that are Sulphureous whether this or any other (as they generally are more or less) to free it the better from it's wild Sulphurs may be calcin'd red hott in the Whole lumps then to be grosly poudered & to be calcin'd a Second time & that chasses away it's Superfluous Sulphurs the best & then your fluxes or Salts do bring it the easier into a Regulus

Again an other Observation is if any Oar be very Sulphery, to treat it by boileing it in a Lee (lixivium) for Which and you beat ye Oar finely to powder & rubb it a while upon a marble or porphire Stone then to boile it a while with ye Lee or Lixivium after that to adulcorate or to wash of the lixivium by fair water & it reduces itself afterwards much easier

Note aqua fortis does not work or operate upon Oars till they have been before hand either calcin'd or oild with a Lee & wash'ed for the Sulphurs cover the metallick part to much & hinders the aqua fortis from acting upon it because no Acid Spiritt touches or operates upon Sulphur Butt note here that if you treat an Oar with a Lee with a Lixivium) that you be Sure to edulcorate it afterwards very well to take away all the lixivious Salts or else the aqua fortis workes only upon the Salts & there Spoiles it's points and not upon the Oar

[p.53] Here follows Some Essays to try Iron upon Gold

Note that Some Iron or Iron oar is goldish, in order to know what gold it has know that ye Iron must be first destroyed (& So it is the Same with Tin) which you doe by putting your Iron upon Lead to Coppell for as the Lead destroyes all inferior mettalls but meliorates gold & Silver So is the Iron here destroyed into Scorys & what gold it has you will find upon the Copple

Note or proceed thus beat your Iron oar into fine powder & with a lothstone draw out of it all what is Ferreous (for it adheres in Small haires to ye lothstone) then with a brush to fetch it off & that So oft as any adhere's to it now take one part of Sulphur, tarter 2 parts nitre 4 parts & of this So prepared oar half as much, being well mixt together have a Crucibell in the fire redd hott carry of the mixture in by Degrees to let it flash & detonate as we call it & this Scorifies the Iron (it brings it to a Scory) then if there be any left yett unscorified detonate it with new flux as before till all the Iron is Scorified or destroyed these Scory's putt into a Crucibell lett them flux & that So long till it becomes as if were a dull glass (Glassy opack Substance) then pour it out into a Cone & if it hath any gold or Silver you will find it at ye bottom like a regulus (it is Curious to See these operations alltho there be no profitt in it) & in this mañer all mettall's or oares may be tried whether [p.54] they hold gold or Silver for here the unfix mettalls are destroyed in the flux, note the Iron may be likewise first melted down with equall parts of antimony into a Scory & then proceed with ye Salts for then ye iron is now more open yett or it may be in that Condition put presently upon a Test to Coppell or to bring it into a Regulus with ye fluxing Salts to bring it into a narrow Compass & then upon ye Coppell & you will See what it holds or noe for

Note this Scoryfieing of mettalls or any Metallick bodies & oars is a thing very materiall & necessary in Essays to come at ye best mettle (vizt gold & Silver) and these Scorifycations must be done with ye fluxing Salts & these Scories you precipitate with Iron charcole dust or lime & there is your regulus at ye bottom of your Crucibell for ye Sulphureous acid part which keept ye Mettall lock't up in the forme of an Oar (as the Chief composition of ye Oar) must be engaged imbib'd as is allready Said by Alkleons body's So that ye Mettall being freed of it's Acidity or Sulphur the heavy part (vizt the metallick part) Sinks then by it's own gravity thorow ye flux down to the bottom of the Crucibell

Note that all Clay or Clayie Substance holds Some thing of Iron & Some Yellow clay holds both Silver & gold So also Bolus and to bring it out take 4 lb of bole 4 [?] pound of Lytharidge & with a good flux of Tarter & nitre to melt it down & Some Salt (kitchen Salt) a top of that for that does gather the Cornells, graines, [p.55] Atoms of Sylver & gold togather, for Lytharidge has noe mañer of Silver as generally Some lead has and therefore Lytharidge is used for Nice Tryalls & Essayes upon gold or Silver & for you to be convinced, that there is Iron or Iron Minera in Clay, look but well upon it with a Microscope & you will easily be convinced

Note if any Oar be Suspected to be Sylverish take thereof one part Lytharidge one part & 2 parts of flux (vizt Tarter & Nitre) & a handfull of kithchen Salt or Sandiver for the Salt is only to gather the graines that lye Scattered up & down the Crucibell & the Sides & this does require a good Strong fire

Note to try the Pirithis which makes ye green Vitriaae if it holds anything Take nitre Tarter & comon Salt of each an Ounce mix it, of this take 2 parts to one of the Stone & flux it down in a Crucibell then a topp of that about ye 8th part of Iron fileings & let it flow (flux) about half an hour & the Iron imbibes ye Sulphur that generally is in the Stone & there will be Some regulus at ye bottom of the Crucibell, break the Crucible & Seperate the Scory's put the regulin part upon lead & coppell it & you will See what it holds.

NOTES AND REFERENCES

1. The somewhat faulty translations of A.A.Barba, **El Arte de los Metales**, and Lazarus Ercker, **Beschreibung... mineralischen Ertzt unnd Berckwercksarten** *(1574)* by Edward Montague *(1674)* and by John Pettus *(1683)* respectively do not represent British practice. Simon Sturtevant's **Metallica** *(1612)*, John Rovenson's **Treatise of Metallica** *(1613)*, and Dud Dudley's **Metallum Martis** *(1665)* were all three litigiously inspired and give scant technical information. Pettus' **Fodinae Regales** *(1670)* is useful only on business organization, while Gabriel Plattes' **Discovery of Subterraneall Treasure** *(1639)*, though well meaning, is brief and unprofessional. John Webster, the author of **Metallographia** *(1671)*, "seems to write like one who never black'd his fingers or sing'd his Beard in metallick Operations" if I may borrow an appropriate phrase applied by the translator of J.A.Cramer *(1941)* to another English author. *(For a more appreciative view of Webster, see A.Debus,* **Actes XII^e Congres International d'Histoire des Sciences 1968** *(Publ. 1971, Vol. 3b, pp. 15-23).* Some manuscript notes of the sixteenth century on the Mines Royal operations are given by M.B.Donald – see below, footnotes 5 and 6.

2. The watermarks are, on one half of each sheet, a double circle about 8.0 cm. diameter, surrounding a crowned shield bearing a lion rampant carrying a sheaf of wheat and a clumsy scimitar, and, on the twin leaf, the letters LVG, 1.1 cm high. The larger device matches exactly the fragments of item 3138 in Edward Heawood, **Watermarks Mainly of the 17th and 18th Centuries** *(Hilversum, 1950).* This was taken from a book by A.Montanus that was printed in Amsterdam in 1668. The letters of the twin mould are smaller and more closely spaced than any of the numerous LVG examples reproduced by Heawood, all of which are of the eighteenth century.

3. M.B.Donald, **Elizabethan Copper. The History of the Mines Royal 1568-1605.** London, 1955.

4. Henry Hamilton. **The English Copper and Brass Industries to 1800.** London, 1926.

5. Donald. Op. cit. pages 369-73.

6. Donald. Op. cit. pages 209-12.

10 October 1974

POSTSCRIPT: A second manuscript of the Notabilia has recently come to light, the text of which is almost identical with the above save in spelling. It was listed in Dawson's (Pall Mall) catalogue no. 246, February 1974, and is now in the personal collection of Mr. Nino Rota of Bari, Italy. It is written in a clear secretary hand, different from that in the Cambridge copy, but approximately contemporary with it. It is divided into six parts, each separately bound in wrappers of figured paper, bearing pasted-on slips of paper with numbers and brief titles. The six parts begin with the title and texts that open pages 1, 6, 16, 30, 39 and 50, respectively, in the Cambridge manuscript.

The illustrations bear the same relation to the text in both manuscripts, though those in Bari are slightly superior in both draftsmanship and technical detail. The words in German script are better formed. Professor Berkowitz suggests that the writing is of about 1690, and he notes that there are features, including an accented 'u', which suggest the hand of a person educated in France or Italy writing carefully in English. Although Bari has a more variable and less modern spelling, some technically strange words in Cambridge appear correctly in Bari.

The following might be noted: "alkalcons" or "alcaleons" in Cambridge, pages 41, 51 and 54 is "alkaleous" in Bari, which also has this word in the blank before "nature" near the bottom of page 5 in C. "Cineres clavellatae" *(C, page 41)* is correct in B, and so are "nuns" for "niens" *(p.6)*, "vitrum saturni" for "nitrum saturni" *(p.47)*, "jahr copper" for "jaht copper" *(p.17)* and "sal armonic" for "salt almoniac" *(p.51)*. The illegible weight of litharge on C, page 54, is, in B, clearly 12 lb.

We should also note that in our transcript above we misread the following words that are correct in both manuscripts: sell vitri for fell vitri *(p.17)* and aridity for acidity *(p.5)*. A double misreading turned the "stoney terrestrial part" in B into the "torrestricis" material of our transcript *(p.16)*.

We conclude that the Bari manuscript is closer to the original version than is Cambridge. Although it is, of course, possible for it to be a later copy from a different earlier one, we believe that it is the actual copy used by the man who a little carelessly transcribed the work into the single slightly more elegant volume now in Massachusetts.

Notes on the development of metallographic studies of ancient iron

B G Scott *

Summary

Research carried out since the war has proved the value of metallography as a tool of archaeological research. However, the idea itself is almost as old as the science of metallurgy, with the first publication of a paper on metallurgical research in archaeology coming in 1881. This paper deals with some of the more important developments in research into ancient iron production, and suggests ways in which future research could profitably be directed.

Introduction

In a situation where archaeologists find themselves more and more involved in trying to construct their models from insufficient basic data, an awareness for the need to introduce new techniques of research has been growing steadily since the end of the last war. There is scarcely a branch of the natural sciences which does not now make a contribution, either through the adaption of research techniques, or application of theoretical concepts. Through this approach of learning from other disciplines, archaeology is gradually being transformed itself into a 'science', with much greater emphasis being placed on the collection of information as the basis for defining the problems which exist, and helping to more precisely formulate the questions which must be asked in order to help solve them. The study of ancient metallurgy has already provided a wealth of information, not only on the manufacture of artifacts, but also on the social and economic organisation which made their production possible. Although perhaps the greater advances have been made in the study of non-ferrous metallurgy, the work of recent years, notably in the Eastern European countries, has led to a considerable widening of our knowledge about ancient iron industries. This paper covers the development of studies on ancient ironworking, in an attempt to show how some of the basic theory has developed, and to try and evaluate the possibilities for the future.

Techniques of metallography evolved from the micrography first developed for petrological studies in the 19th century. One of the first, though unpublished, studies of metallic crystal structure was made by Alois de Widmanstätten in 1808, when he polished and etched the surface of a meteorite and observed the structure which now bears his name *(Mehl 1948, 11)*. Recognition of the crystalline nature of metals came with the work of Sorby and others in the later 19th century. Shortly after this, a French engineer, Victor Tahon, appears to have published the results of 'archaeo-metallographic' studies of ancient ironwork. In all there were three papers published between 1881 and 1889, including metallographic examinations[1]. His work was followed in 1894 by that of Hallbauer who made a metallographic and chemical study of a fragment of ancient iron *(Hallbauer 1894)*. His work seems only to have been prompted by curiosity, while that of Tahon would seem to be the first serious attempt to apply a new technique to archaeological research. In this he would appear to be well ahead of his time.

By 1930, a number of works setting out the results of isolated metallographic studies of ancient ironwork had been published. These were mainly aimed at reconstructing ancient production techniques, and include Gérard's study of Frankish axes (Gérard 1926), Thyssen's work on franciscas *(Thyssen 1927)*, a study of Roman 'soldering' and welding of iron by Newton-Friend *(1928)*. Other examples from this period include the examination of a Roman bloom by Bell *(1912)*, and work by Hanemann on pre-Roman iron artifacts from German sites (*Hanemann 1913, 1922, 1930)*. His studies brought the first isolation of pre-Roman heat-treatment of steel *(Hanemann 1913, 250 – 1; 1922,98)*. There was a tendency, though not pronounced at this stage, towards using the results obtained to evaluate levels of technology in various regions at various periods. This line of purely technological research continues through to the present day, and provides the basis for a large part of our knowledge of production techniques available in antiquity. A logical development has been the highly informative work on pattern-welding by Biek and Anstee *(1961)*. To this, we can add the experimental work on ancient smelting by Wynne and Tylecote *(1958)*, Thomsen *(1964)*, Pleiner *(1969)*, Tylecote et. al., *(1971)*, and others. As well as these, the last decade has also seen detailed metallographic studies designed to clarify problems presented by some of the structures observed in ancient irons and steels. These include study of high-nickel steels, phosphorus contents, and carburisation, by Piaskowski *(1970; 1960, 1965, 1973)*, and the recent work by Tylecote and Thomsen *(1973)* on arsenic and phosphorus segregation. Such work has greatly contributed to the growth of awareness of the need for metallurgists to be prepared to deviate from rigid concepts of modern metallurgical theory, and to be able to project their expertise into an attempt to understand the theory of primitive iron and steel formation and structure.

The second and more important trend in the development of this field, towards the use of metallographic and chemical studies to aid in the construction of specifically regional and/or chronological technological series, can be traced directly back to a paper by Carpenter and Robertson *(1930)* on the metallography of ancient Egyptian iron artifacts. The methods used in this work are open to serious criticism. Having set out to throw light on

* Conservation Laboratory, Ulster Museum, Belfast.

the development of Egyptian iron technology, they only examined nine objects from the whole known period of iron use. They also, in their metallographic work, only examined polished areas of the surfaces of the artifacts. This technique ignores the great tendency towards heterogeneity of iron produced by the bloomery process, which can easily make a surface structure totally unrepresentative of the metal as a whole. Despite these faults, which certainly stem from a lack of understanding of primitive technology, rather than from any lack of expertise, this paper can be considered to mark the start of regional studies on the rise and development of iron industries using metallographic techniques.

The next works of importance are those of Rieth *(1942)*, and Salin and France-Lanord *(1943)*. These workers attempted, through examination of larger numbers of implements, to evaluate technological levels in the Hallstatt and Merovingian periods respectively. As well as the use of metallographic techniques, much greater emphasis was placed on relating the data obtained to the archaeological context. The sizes of the samples *(Rieth 42, Salin and France-Lanord 30)* can in no way be considered statistically reliable nor can the samples themselves be considered random. Apart from the actual technical data they provide *(including the isolation of quenching in a Hallstatt spearhead, by Gilles, in Rieth 1942, 152)*, these works are important from the historical point of view as they mark a further development of the Carpenter-Robertson idea by narrowing down chronological limits. A clearer statement of this was made in a later paper by France-Lanord *(1952, 411)*.

The real breakthrough comes with the work of Kolcin on mediaeval ironworking in Ruthenia *(Kolcin 1953)* in which he carried out detailed metallographic and chemical analyses on 286 artifacts from a total of 32 sites. Because of the tighter territorial limits, and the narrow time-scale *(9th - 12th centuries A.D.)*, and a sample that could be considered statistically reliable, Kolcin was able to apply, for the first time, simple statistical analysis of his numerical data. This programme produced much useful information on the development of iron technology, and the nature of iron production in Ruthenia. Kolcin also appears to have been the first in this work, to attempt to link iron artifacts with specific production centres. Amongst his other work is the very important study of the ironwork from the excavations on mediaeval Novgorod *(Kolcin 1958; see also the summary in Thompson 1967, 71 - 76, especially fig. 74, p.73)*. Since Kolcin's work first appeared, various workers, especially those in Eastern Europe *(e.g. see Piaskowski 1968)*, have developed these ideas further. In recent years, Piaskowski has done extensive work on ancient ironwork from Poland in general *(e.g. Piaskowski 1961, 1969a)*, and in particular, on the iron produced in the extensive smelting sites of the Gory Swietokrzyskie *(Radwan and Bielenin 1956; Piaskowski 1964a)*. In Czechoslovakia, Pleiner has also carried important research into the development of iron smelting technology *(Pleiner 1959)* and ironworking *(Pleiner 1962)*.

The future success of these studies depends on a broadening of specifically regional and chronological research programmes so that we can, first of all, try to gain a basic insight into the character of ancient iron production, both in terms of technology, and also of the economic implications of the establishment and development of iron industries. Small-scale studies of isolated artifacts do not now give an adequate return of information for effort *(in terms of time and money)* expended, unless they can be specifically related to an overall picture of iron production, and placed in proper archaeological context. Certainly the studies of technique, such as those by France-Lanord *(1949)* on pattern-welding, Piaskowski's study of damascened knives *(1964b)*, McGrath's preliminary report on examination of sword-fragments from Llyn Cerrig Bach *(1968)*, and Böhne's work on the development of the so-called Scharsach steel *(1969)* have yielded much information. Their results are of importance because the research has been related to the archaeology of the artifacts examined. Future work must also be directed towards defining as fully as possible the nature and characteristics of iron and steel produced in antiquity *(e.g. Piaskowski 1969b, 1973b)*. This will naturally lead on to the refinement of the work of Kolcin, Piaskowski, and others on the isolation of specific production centres. Closely linked with this work is the research on ore/metal correlation through comparison of chemical compositions. Various workers *(e.g. Thalin 1967; Arrhenius 1967; Haldane 1970)* have produced promising results. However, further work is needed, both in gathering data on ore composition, and also on element partition during smelting *(cf. Tylecote 1962, 253; Piaskowski 1973)*. In the latter case, it may well be found that study of smelting slag, such as that begun by Morton and Wingrove *(1969)* may provide a link *(cf Piaskowski 1965)*. Another field in which much information can be gained is the study of ancient literature. As well as the information provided by classical writers, there is a wealth of references, admittedly mainly oblique, and often ambiguous and obscure, contained in ancient Irish literature, religious, legal, and heroic *(Scott forthcoming)*. A study in depth of not only Irish, but also Welsh and Anglo-Saxon sources can provide much information on the organisation of ancient iron industries. One interesting aspect of this would be research into the development of technical vocabularies caused by the introduction of new technologies, such as iron production. Finally, of course, all of this work must continually be related to the wider perspective of economic and social organisation through archaeological research. This will only come through a realisation by both 'archaeologists' and 'technologists' that such work is not peripheral to, but an integral part of such work.

NOTES AND REFERENCES

(a) Notes

1 Tahon's three papers,
'Les armes franques et leur fabrication en Belgique'
'Les origins de la métallurgie au pays d'Entre-Sambre et Meuse',
'La forgerie du fer chez les francs et pendant le haut moyen age', were apparently published in 1881, 1886 and 1887 respectively. They are referred to by Gérard *(see references, Gérard, E., below)*, but only by title, and with a brief description. I have, so far, been unable to locate the original publications, and would be extremely interested to get further information on them.

(b) References

Arrhenius, O. *(1967)* 'Ore, artifacts, and corrosion', Sveriges Geologiska Undersöknung *(Stockholm)* 61, no.11.

Bell, Sir H. *(1912)* 'Notes on a Bloom of Roman Iron from Corstorpitum', J.Iron and Steel Inst., *(i)* 118 - 135.

Biek, L, and Anstee, P. 'A Study in pattern-welding' Med. Archaeol., 5, 1961, 77-94.

Böhne, C. *(1968)* 'Von Damaststahl zum Scharsachstahl', Archiv für das Eisenhuttenwesen *(Germany)* no.8, 661-665.

Carpenter, Sir H.C.H., and Robertson, J. M. *(1930)* 'The Metallography of some Ancient Egyptian Artifacts', J.Iron and Steel Inst., *(i)* 417 - 454.

France-Lanord, A. *(1949)* 'Le Fabrication des epées damassées mérovingiennes et carolingiènnes', Le Pays Gaumais, Virton, Belgium 1949.

. . . . . *(1952)* 'Les techniques métallurgiques appliquées àl'archaeologie', Révue de Métallurgie *(France)* XLIX *(6)*, 411 - 422, 1952.

Gérard, E. *(1926)* 'Une étude archaéol-métallurgique: La composition de l métal des armes franques', Ann. Soc. Roy. d'Archaeol. Bruxelles, 159 - 165, 1926.

Haldane, W. *(1970)* 'A study of the chemical composition of pre-Roman Ironwork from Somerset', Bull. Hist. Met. Gr., 4*(2)*, 53-66, 1970.

Hallbauer, H. *(1894)* 'Ein Stück historischen Eisens', Stahl und Eisen, 14 *(21)*, 983 - 985, 1894.

Hanemann, H. *(1913)* 'Metallographische Untersuchung Eineger Altkeltischer Und Antiker Eisenfunde', International Zeitschrift für Metallurgie *(Germany)*, IV 248 - 256, 1913.

. . . . . *(1922)* 'Metallographische Untersuchung eineger Altkeltischen Eisenfunde von der Steinsberg', Prähistorisches Zeitschrift *(Germany)* XIII, 94 - 98, 1922.

. . . . . *(1930)* 'Untersuchung eines eiserner Spitzbarrens auf der vorrömischer Zeit', Prähistorisches Zeitschrift *(Germany)*, 21, 271 - 275, 1930.

Kolcin, B. *(1953)* 'Cernaja metallurgija i metalloobrabotka v drevnej Rusi', Materialy i Issledowassifa po Archaeologu SSSR *(Russia)*, 32 7ffm 1953.

. . . . . *(1958)* 'Works of the Novgorod Expedition', VII, Moscow, 1958.

McGrath, J.N. *(1968)* Preliminary report on the metallographic examination of four fragmentary Early Iron Age sword blades from Llyn Cerrig Bach Bull. Hist. Met. Gr. 2 *(2)*, 78 - 80, 1968.

Mehl, R.F. *(1948)* 'A brief history of the science of metals', New York, 1948.

Newton-Friend, J. *(1928)* 'An Example of Roman 'Soldering' and Welding from Uriconium', J. Inst. Metals, XXXIX *(1)*, 61 - 62, 1928.

Piaskowski, J. *(1960)* 'Naweglanie zelaza w dawnych wiekach', Prezgad Mechaniczny *(Poland)*, XIX, no.5, 130ff.

. . . . . *(1961)* 'Metallographic investigations of iron objects from the territory between the Oder and basin of the Vistula', J.Iron and Steel Inst., 198, 263 - 281, 1961.

Piaskowski, J. *(1964a)* 'The method of determination of the origin of ancient iron objects based on metallographic investigations', Archaeol. Polonia, VI, 124 - 160, 1964.

Piaskowski J. *(1964b)* 'The manufacture of Medieval Damascened knives' J.Iron & Steel Inst. 202 *(2)*, 561-8, 1964.

..... *(1965)* **'Correlation between the phosphorus content of slag and that of bloomery iron', Archaeol. Polonia, VII,** 83 - 103, 1965.

..... *(1968)* 'Le sviluppo degli studi metallurgici su antichi ogetti di ferre in Polonia', **La Metallurgia Italiana** *(Italy)* 1968.

..... *(1969a)* 'Achievements of research carried out in Poland on the early technology of iron', **Archaeol. Polonia, XII,** 187 - 215, 1969.

..... *(1969b)* 'Cechy materiaow-technologiczne wyrobów zelanznych jako kryteria kulturowo-chronologiczne', **Wiadmosci Archaeologiczna** *(Poland)* **XXXIV,** 3 - 4, 332 - 354, 1969.

..... *(1970)* 'O Produkji Zelaza wysokoniklowego w starozytnosci', **Acta Archaeol. Carpathica, XI** *(2),* 319 - 328, 1970.

..... *(1973a)* 'Zaleznošč pomiedzy zwartŏscia forsforu w rudzie lub zuzlu i zelazie dymarskim' **Stud. Mater. Dziejow Nauki Polskiej,** ser. d, 7, 39 - 69, 1973.

Pleiner, R. *(1958)* 'Základy Slovanského Zelezárského Hutnictví v Ceských Zemíchi', Prague, 1958.

Pleiner, R. *(1969)* 'Experimental Smelting of Steel in Early Mediaeval Furnaces' Pamatky Archaeologické LX, 458 - 487, 1969.

Radwan, M. and Bielenin, K. *(1960)* 'Iron smelting in the Swiety Krzyz Mountains at the Beginning of our Era', **Kwartalnik Historic Kultury Materianej** *(Poland),* VI, 1/2, supplement, 277 - 287, 1960.

Rieth, A. *(1942)* **'Der Eisentechnik der Hallstattzeit,** Leipzig, *(1942).*

Salin, E., and France-Lanord A. *(1943)* **Rhin et Orient,** II Paris, 1943.

Thalin, L. *(1967)* **'Svenskt förhistorisk järn - ett forskningsprojekt' Jernkontorets Annaler,** 151 *(5),* 305 - 324, 1967.

Thompson, M.W. *(1967)* **Novgorod the Great,** London, 1967.

Thomson, R *(1964)* **'Trial reconstruction of an early process of iron production', Kuml,** 60 - 74, 1964.

Thyssen, F. *(1927)* **'Contribution à l'Etude de Procédès de Fabrication des Haches sous la Période Franque' Chron. Archaeol. Pays due Liége,** 53 - 62, 1927.

Tylecote, R.F. *(1962)* **Metallurgy in Archaeology,** London 1962.

Tylecote, R.F., Austin, J.N., and Wraith, A.E. *(1971)* **'The mechanism of the bloomery process in shaft furnaces', J.Iron and Steel Inst.,** 1971, 342 - 363

..... and Thomsen, R. *(1973)* **'The segregation and surface-enrichment of arsenic and phosphorus in early iron artifacts', Archaeometry,** 15 *(2),* 193 - 198, 1973.

Wynne, E.J. and Tylecote, R.F. *(1958)* **'An experimental investigation into primitive iron, smelting technique', J.Iron and Steel Inst.,** 190, 339 - 348, 1958.

The metallographic examination of a Burgkmair etching plate in the British Museum

A.R. Williams
(Department of History of Science and Technology, UMIST)

In the course of my research into medieval armour, I felt that an examination of other contemporary steel objects might be useful. The Department of Prints and Drawings of the British Museum very kindly allowed me to examine the original etching plate of Hans Burgkmair's* "Mercury & Venus" in the British Museum Laboratories; with the proviso that such examination had to be entirely non-destructive.

Accordingly, I fastened the plate between two blocks of wood, which enabled it to be held at a constant angle, and polished an area *(about 2mm x 10mm)* of an edge of the plate on 4 grades of emery and 2 of diamond. The rest of the plate's edge was protected with cellotape during this operation. The polished edge was then etched with 2% nital and examined microscopically.

Figure 1. (x 75) shows that the steel is laminated in strucuture, alternate layers of light- and dark-etching material being visible. Approximately 3 darker areas can be seen to alternate with 3 lighter areas in the upper half of the section. One edge of the plate is pitted by corrosion and a large crack runs down the centre, together with a few streaks of slag. The randomly-scattered lines are polishing scratches and are due to the difficulty of getting a uniformly flat surface on a specimen as large as this.

Figure 2. (x 110) shows that the dark-etching areas consist of large pearlite areas surrounded by smaller grains of ferrite *(perhaps 0.7%)*. The lighter areas all consist of a mixture of smaller pearlite areas and ferrite grains in approximately equal amounts *(perhaps 0.4%C)*.

Figure 3. (x 340) shows that the cementite has started to agglomerate in places. In other parts, the lamellar nature of the pearlite is more conspicuous.

Discussion:

The plate may have been made from a number of sheets of wrought iron carburised and forged together in a pile.

An analogous method *(the piling and forging of carburised strips)* had been used for making sword-blades and spear-heads since the fourth century BC.(2)

On the other hand, without sectioning the plate to see how continuous the layering is, it is not possible to say whether or not, it is simply the consequence of forging a heterogeneous bloom.

Recent experiments with shaft furnaces(3) have shown that the medieval process could in fact produce a medium-carbon-steel bloom directly, and the folding and hammering of such a bloom into sheet could produce a layered effect.

The pearlite areas do not show distortion, so the plate was forged above the A_3 temperature; although it was not kept at this temperature sufficiently long for austenitic grain growth to eradicate traces of the laminae.

* (1473-1531) one of the earliest German artists of the Renaissance (1)

ACKNOWLEDGMENTS:

I would like to thank Mr.Edward Croft-Murray, Keeper of the Department of Prints and Drawings at the British Museum, for permission to study the plate, and Dr.A.E.Werner, Director of the Research Laboratories there for allowing me to make use of his laboratory facilities, and the assistance of his staff.

PHOTOGRAPH:

REFERENCES:

(1) HIND, A.M. "A History of Engraving and Etching" *(1923, p.109, reprinted 1963)*.

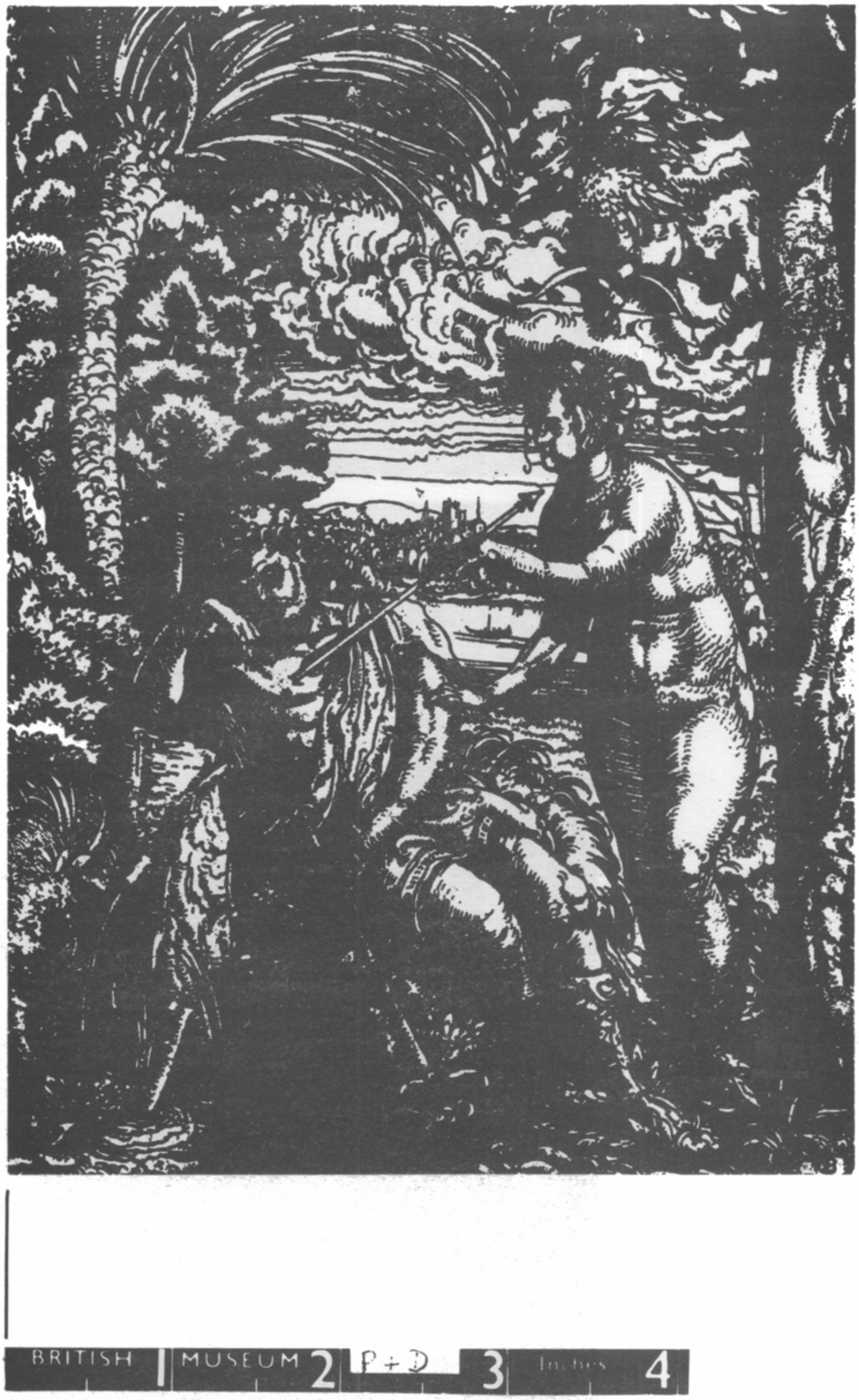
(2) The technique of "piling" carburised strips of iron for sword-blades or spearheads was known to the Etruscans *(ca. 4th century BC)* and Celts *(ca. 2nd century BC)* and possibly to others.

REGGIORI, A. and GARNO, C. "Esame tecnologico di un gruppo di spade galliche della lombardia mord-occidentale" in Sibrium, 2, 43. *(1955-6)*.

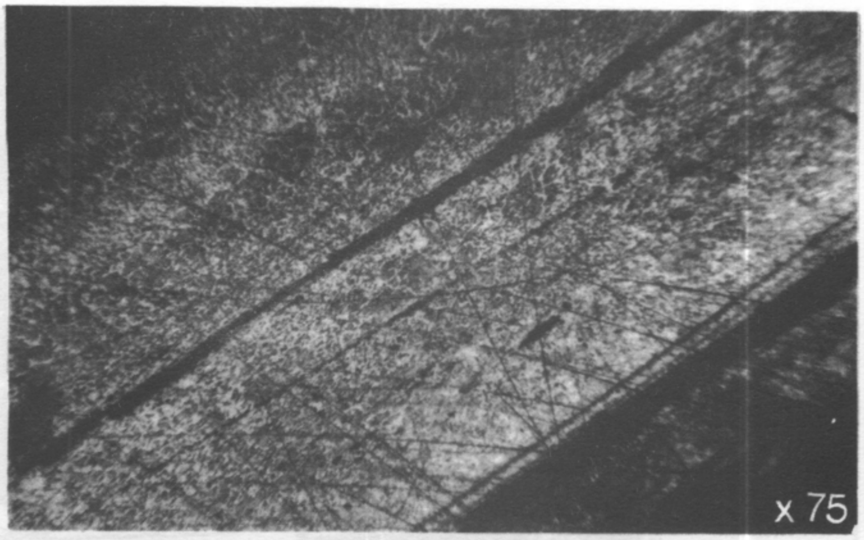
and

PANSERI, C. "Damascus steel in legend and in reality". in Gladius, 4, 5. *(on an Etruscan spearhead, p.33) (1965)*

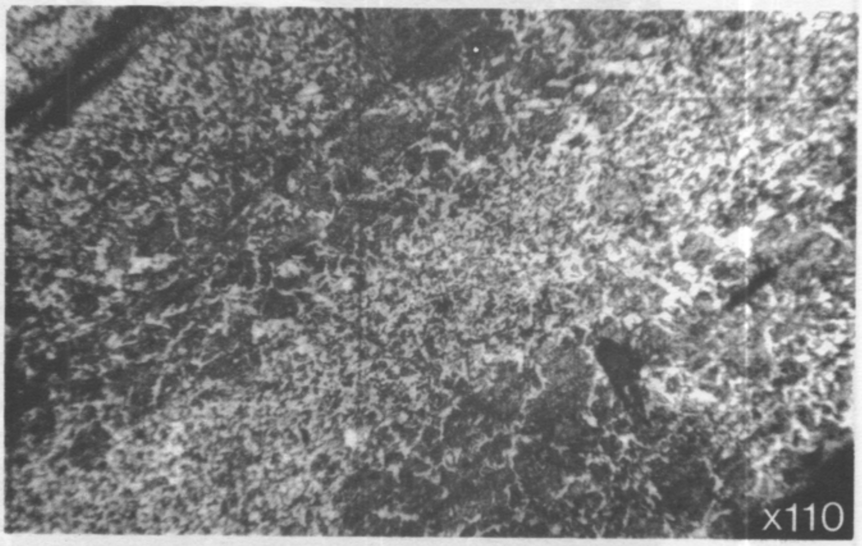
(3) TYLECOTE, R.F., "The mechanism of the bloomery process in shaft furnaces". Journal of the Iron & Steel Institute *(1971)* 342.


BRITISH 1 MUSEUM 2 P+D 3 Inches 4

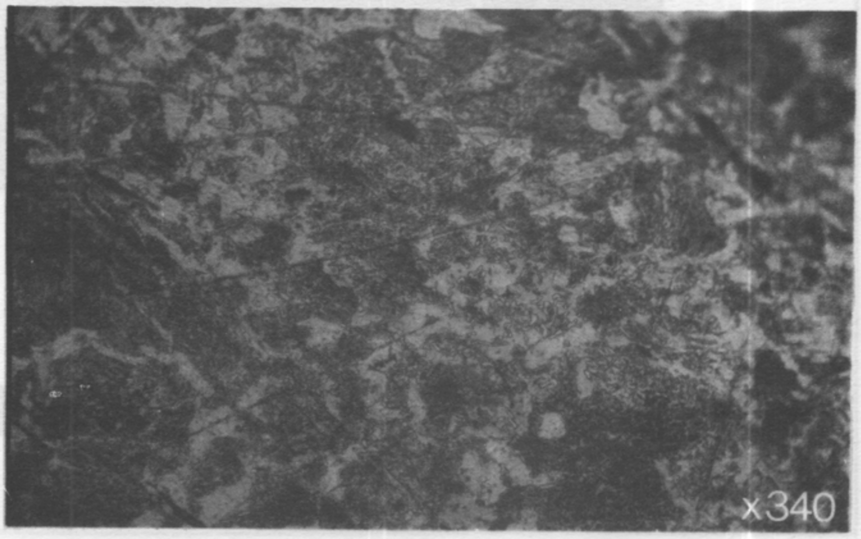
A cross-section of the edge of the plate

1 

The dark-etching (pearlite) and light-etching (pearlite/ferrite) areas

2 

Close-up of the ferrite/pearlite areas. The duplex nature of the pearlite is apparent.

3 

Materials testing in classical Greece

TECHNICAL SPECIFICATIONS IN THE 4TH CENTURY AD.

An inscribed stele tablet under investigation by Dr Varoufakis was found in 1893 at Eleusis and belongs to the 4th century BC; it refers to a decree and concerns the manufacture of bronse fittings *(known as "empolia" and "poloi")*for the erection of the columns of Philonian Stoa; the latter name derives from its architect Philon, who undertook to build the portico *(stoa)* of the Telestirion during the 4th century BC. The inscribed stele which is in the museum of Eleusis demonstrates the high technical standard achieved by ancient Greeks in metallurgy.
Dr Varoufakis is examining the inscription in the light of historical metallurgy in an endeavour to assess contemporary technical knowledge in the making and testing of metals and their alloys.

Before the 4th century, fittings for the assembly of the column drums were made of hard wood: cedar for the "empolia" and olive for the "poloi" *(cylindrical dowels mortised into the cubical blocks of "empolia" which being set in the drums permitted their safe and accurate fixing).* Dr Varoufakis is considering reasons for the substitution of wood by the much harder copper-tin alloy-bronze. An interesting point mentioned in this inscription is the use of the lathe for the shaping of this hard alloy into the cylindrical form of "polos" having a specified diameter. This involved the use of a cutting tool much harder than bronze; beyond doubt this was a heat-treated hard steel.

The second and probably the more important part of his investigation refers to the "chemical specifications" according to which the column drum fittings should be produced by the supplier. The bronze was to contain eleven parts of copper and one part of tin *(ie 91.67%:8.33%).* He considers that the contractor or the inspector could check whether the bronze fittings composition was according to the requirements of the stated specifications. He believes that some kind of quality control existed, otherwise the given chemical specifications would be of no value. There were also two main reasons imposing quality control on the fittings : (a) The mechanical properties of bronze depend largely on its chemical composition. Copper-tin alloy is harder, the higher its tin content. Therefore, if the tin was lower than specified, the bronze would be softer and its mechanical properties would be deficient for the given structural purposes, (b) the inspector would have to know the approximate alloy composition because the price of bronze was based upon its tin content, since its value was six and a half times higher than that of copper. The manufacturer would, therefore, be inclined to supply a poorer and consequently a cheaper and for him a more profitable copper-tin alloy if he knew that no control existed.

Finally, the fact that the inspection constitutes a decree underlines the importance of the stated technical specifications and the obligations undertaken by both the supplier and the quality control inspector.
Dr Varoufakis is evaluating two possible ways of checking the alloy composition:

(a) a comparison between the colours of the supplied bronze and a set of copper-tin alloys of known compositions, all alloys being well polished. He carried out an experiment and observed that it would be possible to classify approximately a bronze of an unknown composition by comparing it with a set of standard copper-tin alloys. A similar process, known as "the Lydia Lithos Touchstone" method was used in antiquity to identify the purity of gold objects and to differentiate gold alloys composition. A development of this process is still used by goldsmiths.

(b) qualitative hardness test could be another possible test of the copper alloy composition. In this case the metal to be checked would be annealed before testing in order to eliminate any internal stress due probably to previous cold work treatment and thus restore its original mechanical properties, which would correspond to its chemical composition. This test, if ever used, would always be done on a comparison basis, as in the above mentioned case of colour matching.

Further archaeological research may throw more light on the subject of testing the metal composition in antiquity and fill the gaps of our knowledge in this field.

A note on investigations by Dr George J Varoufakis, Athens, communicated by Mr M L Pearl of the Metals Society, London.

The present day production of wrought iron

by G R Morton FIM and
*R G Birt**

The purpose of this paper is to examine the present day techniques used in the production of wrought iron, and to compare them with the traditional methods of working. The practice employed at the Bolton Works of Thomas Walmsley & Sons Limited, was observed and compared with records of heats at Bromford Ironworks in 1859, and at Black Country Forge in 1951.

Samples of all raw materials were taken and analysed, and also samples of iron and slag throughout the production cycle. As far as is known, this is the first time that any detailed analysis of the puddling process at all stages of production has been obtained.

WROUGHT IRON – DEFINITION

Wrought iron has been defined as "commercially pure iron, which having been produced in a pasty condition, is always associated with more or less intermingled slag".

It is produced by refining pig iron in a reverberatory type of furnace with oxide of iron. The purified iron obtained is a pasty mass intermingled with slag which contains the impurities. This slag is then squeezed out of the pasty ball of iron by hot working ie shingling or muck rolling.

A small amount of slag always remains as iron silicates, which gives the iron its characteristic fibrous appearance due to the fact that slag particles surrounding the granules of iron, causes them to assume an elongated structure on hot rolling.

This fibrous structure can be clearly seen when a bar of wrought iron is nicked on one side and bent over. The regularity of the fibre is an indication of the uniformity of the iron granules. This is therefore a convenient test for the quality of wrought iron. When nicked on both sides of the bar, a clean crystalline fracture is seen.

Wrought iron melts at 1500°C, but below this temperature, the contained slag melts and the metal assumes its pasty condition. In this state it can be easily hammer welded.

THE PUDDLING FURNACE

The traditional puddling furnace was a reverberatory furnace built up from firebrick encased by cast iron plates. The whole structure was tied together with wrought iron rods. A firebrick roof of sprung arch construction covered the furnace. The bottom of the furnace was built up on a bed of cast iron plates which rested in a cast iron framework. The hearth was built up from iron oxide on top of this bed.

Early furnaces had bottoms formed from basic materials produced in the old charcoal refineries, but scarcity of these materials brought about the use of calcined tap cinder. Tap cinder was the slag produced in the process itself, and when calcined, some of the contained ferrous silicate was oxidised to form ferric silicate, rendering it more refractory and capable of supplying oxygen to the charge. Other materials such as mill scale or hammer scale were also used in a finely crushed form mixed with water. All these materials formed a liquid bed of oxide under the charge, which gave rise to the term "Wet Process".

The fire grate was constructed of wrought iron bars, and was large in proportion to the hearth because of the very high temperatures required, particularly in the later stages of the process. The working side of the furnace was provided with suitable openings for the fire hole and working door, and each furnace was equipped with a separate flue leading to a rectangular stack, which was fitted with an iron damper to control the draught. The fire bridge between the grate and the hearth was of cast iron protected by firebrick, and was provided with means of air cooling.

The furnace was manned by two men, the puddler and his underhand.

The procedure for building up the hearth of a newly built furnace was as follows:

Fettling material such as best tap cinder, was broken into small pieces and spread over the cast iron plates to a depth of two or three inches. Mill scale or other finer material was then added and the hearth levelled. The fire was then lit and a good heat, sufficient to make the materials cohere, was obtained. A quantity of scrap was then charged into the furnace, heated to a welding temperature of around 1450°C and formed into a ball. The ball was then worked repeatedly over the bottom.

In this way a quantity of magnetic oxide was produced which flowed over the hearth and united the materials into a smooth, solid, non-conducting mass.

After making the bottom in this way, the puddler proceeded to charge fettling materials and arranged these to form a shallow dish shape which was to contain the charge. Larger lumps of fettling material were charged around the sides and against the firebridge, in order to protect it as far as possible from excessive heat. Similar material of smaller size was added to fill up the spaces between the larger lumps, and ground purple ore or 'bull dog', damped with water to act as a bonding agent, was placed on to form the final dish shape.

The hearth produced by the above method was basic in nature, and contained considerable quantities of free iron oxide in a matrix of fayalite.

Fettling materials used varied according to the type of pig iron used. The purer grades of pig iron produced less slag, and therefore required a fusible fettling material, the most common type being hammer slag or the cinder obtained from the compression of puddle balls. This material resembled tap cinder in composition but was somewhat richer.

* R G Birt is at the BSC Divisional Training Centre, Hathersage.

High silicon and phosphorus irons would "cut back" a fusible lining and therefore required a more refractory or infusible fettling material.

Typical analyses of the above materials are set out in Table 1.

a relatively low temperature and a basic slag. Manganese was removed early in the process although if the quantity was high the carbon boil may have been delayed. Sulphur was only partially removed, this being one of the objections to white iron, as it is liable to high sulphur.

TABLE 1

ANALYSIS OF TYPICAL FETTLING MATERIALS (%)

Material	FeO	Fe_2O_3	SiO_2	CaO	MgO	MnO	Al_2O_3	P	S
"Bull Dog"	39.83	23.75	23.86	0.28	0.24	6.17	0.91	6.42	–
Best Tap	67.46	25.86	3.05	0.26	0.40	1.30	0.35	0.87	Trace
"Blue Billy"	46.53	0.65	2.95	2.44	1.39	2.54	1.27	0.69	0.16

NOTE: "Blue Billy" also contains : 30.54% CO_2 :
6.57% Carbonaceous Matter

PIG IRON USED

One advantage of the puddling process is that use can be made of pig iron of varying composition. Until recent years pig iron was graded according to the appearance of its fractured surface. South Staffordshire 'All Mine' iron was graded by numbers from 1 to 8, the lower numbers being open grained grey iron and the higher numbers passing from mottled to white iron. A more general system of grading was by numbers from 1 to 4. Number 4 Forge was the iron usually recommended for use in the puddling process.

Analyses of South Staffordshire "All Mine' irons are set out in Table 2.

The amount of carbon present had a profound effect on the removal of other impurities as it tended to prolong the boil. Silicon is one of the most important constituents in determining the suitability of an iron for puddling. Usually this lay between one and two percent. All the silicon was converted to ferrous silicate as $2FeO\ SiO_2$, each 28 parts of silicon combining with 125 parts of iron and passing into the slag. From this we can see that for every 1% of silicon in the iron a 4% loss of iron was obtained, therefore, a large percentage of silicon was avoided.

Phosphorus is always an objectional constituent since any residual renders the iron cold short. This was removed before the carbon boil, its oxidation being favoured by

WORKING A CHARGE

The working of a heat of iron in a puddling furnace can be divided into four stages:-

Stage 1 – The Melting Period

After the furnace had been fettled, the charge of pig iron was lifted into the hearth by hand. The charge usually weighed about 4½ cwts, in eight or nine large lumps which were thrown on top of the fettled hearth. The fire hole was then stopped with slack and the furnace door closed to prevent the entry of air. As the charge began to soften, the individual pieces were turned over to assist the melting process. Unmelted pieces were rabbled to the surface to encourage complete fusion.

During the melting period which lasted about thirty minutes, most of the silicon and some of the phosphorus was oxidised.

Stage 2 – The Clearing Period

The charge at the end of the melting period was covered with slag and was in a state of 'quiet fusion'. The whole bath was then stirred with a bar thus exposing the iron to the iron oxide fettling. This process took about ten minutes, during which time the remaining silicon and manganese were oxidised and the phosphorus further reduced.

TABLE 2

TYPICAL ANALYSES OF SOUTH STAFFORDSHIRE 'ALL MINE' PIG IRONS (Weight %)

	No.1	No.2	No.3	No.4	No.5	No.6	White
T.C.	3.70	3.13	2.95	2.64	2.46	2.25	2.20
Si	1.88	1.72	1.92	1.33	0.97	1.09	0.71
Mn	0.40	0.54	0.40	0.25	0.52	0.46	0.50
P	0.71	0.68	0.52	0.56	0.51	0.48	0.47
S	0.02	0.04	0.07	0.09	0.12	0.17	0.16

Stage 3 – The Boil

The furnace damper was then lowered so as to lower the temperature and to establish a somewhat reducing atmosphere in the hearth. The melt was then vigorously stirred so that the molten charge was thoroughly mixed with iron oxide.

The carbon began to oxidise, being expelled as carbon monoxide, which later burnt to carbon dioxide in the furnace. Short blue flames issued from the melt: these were known as 'Puddlers Candles'. The escaping carbon monoxide gas bubbled up through the liquid iron giving it the appearance of boiling. The slag, being frothed up, boiled over the door sill into a cast iron pot. On occasion, all the slag was not expelled in this manner and the puddler had to tap off the excess by ramming through the fettling with an iron bar. This was considered to be bad practice, and the puddler guilty of this was liable to dismissal. As the carbon was oxidised, the melting point of the iron was raised, causing it to assume its pasty state. The boil lasted for about thirty minutes.

Stage 4 – The Balling Up Stage

The iron became more and more difficult to work as the boil diminished, and could be seen as a mass of bright granules. The temperature was then raised as high as possible and the charge worked constantly until the iron 'came to nature' or assumed the state of bright granules of malleable iron. The individual granules were only moderately fused together so it was fairly easy to break the charge into several balls with a bar. Each ball, weighing about 100 - 120 lbs, was then manoeuvred to the front of the furnace and removed in turn using a large pair of tongs.

The balls were then quickly carried to a shingling hammer which squashed out a large part of the intermingled slag. The rough bloom produced by shingling was rolled at once to remove slag.

This shingled and once rolled product was known as 'Muck Bar'. A higher grade of wrought iron was produced by remelting muck bar in a piling furnace followed by a further hammering and rolling. This process could be carried out up to three or four times depending on the grade of wrought iron required.

In the great days the standard practice was (1) Make muck bar from puddled balls. Sometimes this was rolled to finished size and sold, but not as a rule, and never by the most reputable firms; (2) Shear cold muck bar, pile, re-heat and re-roll to make crown iron; (3) Repeat with crown iron to make Best; (4) Repeat with Best to make Best Best or BB; (5) Repeat with BB to make Best Best Best or BBB. Most firms did not go beyond BB and some not this far. BBB was uncommon.[1]

DETAILS OF A HEAT AT BROMFORD IRONWORKS IN JULY 1859[2]

Time		
Hrs.	Mins.	
		The cinder having been tapped off, and the furnace being supposed to be ready for the next heat. The charge consisted of a mixture of 1 cwt of refined iron and 3 cwt of forge pig iron together with 1 cwt of hammer scale.
0	0	Hammer scale was put in and spread over the bed and round the sides. This charging was effected in about 3 minutes, the damper being up all the while. The door was let down and wedged and the stopper hole was closed up with a bit of bar iron. Coal was introduced and the fire 'fettled'.

Time Hrs.	Mins.	
0	19	The underhand put coal on. The puddler lifted or moved about the pig iron through the stopper hole with his paddle.
0	35	All the pig iron was now completely melted. The damper was not let down.
0	46	The fire was made up by the underhand, the stirring having continued without interruption. The damper was raised.
0	50	The molten metal presented the appearance of ebullition (Boiling) jets of blue flame escaping everywhere from its surface.
1	03	Much of the iron had 'come to nature'. Percy mentions the puddler and the underhand working the iron with the damper 'still continuing up'. This was presumably the balling up operation.
1	15	The first ball was taken out. The damper was partially let down and the stopper hole closed. The body of the furnace was now full of smokey, reducing flames.
1	16	The second ball was taken out.
1	19	The third ball was taken out.
1	21	The fourth ball taken out.
1	23	The fifth ball was taken out.
1	24	The sixth and last ball was taken out.

Summary		
	Melting down	35 minutes
	Smothering	11 minutes
	Boiling	17 minutes
	Balling up	21 minutes
	TOTAL:	1 hr 24 minutes

DETAILS OF HEAT AT B   CK COUNTRY FORGE IN MARCH 1953

Time Hrs.	Mins.	
		The furnace having been cleared and the cinder tapped off from the previous heat, the cinder tap hole was closed with sand and a little light fettling was thrown through the working door. The furnace had a good bottom and repairs were not necessary. Coal was added to the fire and the underhand cleared the firebars.
0	0	The underhand charged 5 cwt of pig iron. The working door was closed, wedged and a shovelful of mill scale thrown across the bottom of the door to seal it. The stopper hole was closed with a piece of steel plate. Melting down began.
0	10	The fire was coaled by the underhand.
0	12	The stopper hole was opened and the paddle inserted to move the pigs about to promote melting.
0	17	The pigs were turned several times to ensure complete fusion.
0	30	The metal began to work and the damper was lowered for the smothering period.
0	33	More coal was added to the fire.
0	40	The damper was raised a little and the smothering ended. The puddler took the rabble and began rabbling steadily.
0	41	The metal was now boiling violently and 'puddlers candles' were much in evidence. Some cinder boiled over the foreplate.
1	15	The iron had completely come to nature. The damper was put right down to prevent unnecessary oxidation and the puddler began to quarter the iron with the paddle. He then took the rabble and drew the first ball to the front of the furnace.
1	17	The damper was raised a little and the door wedges knocked out. The working door was then opened. The first ball was taken out.
1	18	The second ball was taken out.
1	21	The third ball was taken out.
1	22	The fourth ball was taken out.
1	24	The remaining iron in the furnace was worked into a small ball and this last ball was taken out.

Summary		
	Melting down	30 minutes
	Smothering	10 minutes
	Boiling	35 minutes
	Balling up	9 minutes
	TOTAL:	1 hr 24 minutes

DETAILS OF HEAT AT THOS. WALMSLEY & SONS LIMITED, BOLTON, LANCS.

Recorded Wednesday, 29th March 1972.

Time

1117 The furnace, being ready for the next heat, was fettled round the banks with ball furnace slag. This material, in lumps of approximately 6", was sampled and analysed. The following analysis was obtained which compares quite closely with that of Best Tap. See Table 1.

	FeO	Fe_2O_3	SiO_2	CaO	MgO	MnO	Al_2O_3	P	S
%	66.02	27.00	2.60	1.02	0.46	1.42	0.64	0.75	0.06

1119 The door was closed, the furnace now being under heat.

1123 Hot water was poured onto the hearth in order to chill it. The purpose of this chilling is to prevent the lump charge from sinking into the soft bottom and so damaging it.

1125 Purple ore mixed with water was charged over the lump ball furnace banks. This produced a smooth saucer shaped lining to the hearth. The ore was sampled and analysed as follows:-

	Fe_2O_3	SiO_2	CaO	MgO	Al_2O_3	P_2O_5	SO_2	Ignition Loss
%	57.60	7.24	1.20	1.39	1.20	0.36	1.20	27.80

1126 Charging now commenced. Lumps of scrap wrought iron, varying in weight from 50 - 100 lbs, were put into the furnace by hand. A few shovelfuls of mixed small cinder and fine scrap were added followed by lumps of Indian pig iron. This pig iron was supplied in whole pigs, and was broken into small lumps before being charged. A sample was taken and analysed as follows:-

	T.C.	Mn	Si	S	P	Cu	Ni	Cr	Mo	Sn
%	3.56	0.18	2.35	.091	0.71	.04	.02	.08	.005	Trace

The approximate weight of the charge was 5½ cwt comprising 60% scrap and 40% pig iron.

1129 The furnace now being fully charged, the door was closed and a steel plate was placed over the working hole. The heat was full on.

1140 The puddler turned over the pig iron lumps using a bar to assist melting.

1148 Further turning over of the charge took place until 1210.

1210 A lump of material which was reluctant to melt was removed from the furnace. This proved to be a piece of cast steel weighing approximately 14 lbs.

1212 Rabbling commenced; the puddler working the charge constantly for several minutes.

1214 The damper was lowered to smother the furnace.

1216 On looking into the furnace a slight trace of the boil could be seen.

1218 The cinder bogie was placed in position beneath the working door.

1220 The boil was now starting and iron and slag samples were taken.

Rabbling was continued and the damper was opened.

Analysis of iron at start of boil:

	T.C.	Mn	Si	S	P	Cu	Ni	Cr	Mo	Sn
%	3.34	.14	.23	.023	.56	.04	.02	.06	.005	Trace

Analysis of slag at start of boil:

	SiO_2	Al_2O_3	CaO	MgO	FeO	P_2O_5	MnO	CaS
%	19.40	2.64	1.70	1.17	70.50	1.68	1.34	1.46

1230 The boil was now subsiding and slag starting to boil over the door sill. A sample was taken of this slag and analysed.

	SiO_2	Al_2O_3	CaO	MgO	FeO	P_2O_5	MnO	CaS%
%	19.60	2.60	1.70	1.15	70.00	2.05	1.37	1.52

Comparing this slag with the start of boil slag, it will be noted that there is no appreciable rise in SiO_2 or MnO, suggesting that most of the silicon and manganese had been oxidised at the start of the boil. Phosphorus was oxidised during the boil, causing a rise in P_2O_5.

1232 The iron was now coming to nature and the characteristic "falling rice" appearance could be seen. Rabbling continued.

1248 All the slag had not boiled off, so it was tapped off by driving an iron bar through the fettling on the furnace bottom. A sample of this slag showed a drop of 0.23% P_2O_5 indicating a slight phosphorus reversal. This was possibly brought about by an increase in temperature.

	SiO_2	Al_2O_3	CaO	MgO	FeO	P_2O_5	MnO	CaS
%	19.60	2.40	1.68	1.15	70.50	1.82	1.37	1.48

1250 The puddler started to ball up the charge.

1257 The damper was closed.

1300 The first ball was removed and transferred to the shingling hammer.

1304 The second ball was removed.

1307 The third ball was removed.

1309 The fourth ball was removed.

Samples of the balled up iron were taken and analysed as follows:-

	C	Mn	S	P	Si	Cu	Ni	Cr	Mo	Sn
%	.068	.020	.011	.009	–	.03	.02	.02	.004	Trace

When the iron had been roughly shingled, a further sample was taken and analysed:-

	C	Mn	S	P	Si	Cu	Ni	Cr	Mo	Sn
%	.062	.02	.011	.005	–	.03	.02	.02	.004	Trace

It was noted that the phosphorus was reduced simply by squeezing out some of the slag. On further hot working by rolling into muck bar the phosphorus was further reduced to .004%.

A further sample of Best Wrought Iron was obtained at a later date, which had been produced by reheating muck bar together with wrought iron scrap. This was done in a furnace with a flat hearth which sloped gently towards the chimney. The materials were assembled and cut into small pieces and made into 'parcels' or piles about twelve inches square. After charging into the furnace, these were heated to welding heat until the piles began to sag. Some of the slag melted out of the wrought iron and was tapped off continuously into a bogie. The piles were removed from the furnace and hot rolled as before. A sample of this material was obtained and analysed.

Analysis of Best Wrought Iron

	C	Mn	S	P	Si	Cu	Ni	Cr	Mo	Sn
%	.050	.017	.010	.003	–	.03	.02	.02	.004	Trace

A higher grade of wrought iron is produced by further remelting and hot working. This iron is known as 'Treble Best'.

Summary:

Melting down	43 minutes
Smothering	6 minutes
Boiling	10 minutes
Balling up	39 minutes
TOTAL	1 hr 38 minutes

From the above analysis it can be seen that the iron contains a small amount of phosphorus (0.003%).

The sample for this analysis was prepared by conventional methods, ie pulverising lumps of wrought iron and screening to a suitable size for analysis. Obviously this sample contains both wrought iron and its intermingled slag. It was, therefore, decided to separate the iron from the slag and analyse each individually. A sample of 'Best Wrought Iron' was prepared and carefully separated magnetically. The analysis of the iron and slag was as follows:-

Iron

	C	Mn	S	P	Si	Cu	Ni	Cr	Mo	Sn
%	.05	.010	.010	Trace	–	.03	.02	.02	.004	Trace

Slag

	SiO_2	Al_2O_3	CaO	MgO	FeO	P_2O_5	MnO	CaS
%	19.40	2.20	1.64	1.15	70.70	1.80	1.30	1.30

From the above analysis it will be seen that the actual iron contains little or no phosphorus; the small amount shown in the original analysis being contained in particles of intermingled slag.

This also follows to a lesser extent in the case of manganese. Almost half of the total manganese shown originally being contained in the slag as manganese oxide.

CONCLUSIONS

A comparison of the foregoing practices shows very little difference between traditional and present day methods.

The puddling at Thomas Walmsley & Sons Limited, is carried out in a furnace of conventional design – the one concession to modern times being the replacement of the coal fire with an oil burner. A longer melt down stage was no doubt due to the fact that a heavier charge was used, and not that the furnace was less efficient using liquid fuel.

The actual refining time was shorter but otherwise followed traditional lines.

No analysis of the heats at Bromford and Black Country Forge were available so it is impossible to make any comparisons in this respect. As stated earlier this is the first time, as far as is known, that any detailed analysis has been carried out on a heat in the puddling process. However, the times of the various changes taking place in the furnace bear a close resemblance to each other so it is not unreasonable to suppose that the removal of metalloids in the early heats was no different or less efficient than the modern heat observed.

All these observations point to the fact that no significant improvements have come to light in the puddling process since its early days.

ACKNOWLEDGEMENTS

Acknowledgements are due to Mr J H Mitton, Manager, Education and Training, British Steel Corporation, Bilston Works, for permission to carry out the necessary analysis for this project; to Mrs P Hudson without whose sterling work at the typewriter, this paper could not have come to fruition; and to Mrs A Morton for reading and correcting the original proof.

REFERENCES

1. W K V Gale – Personal communication.
2. J Percy – Metallurgy, Iron and Steel, London, 1864 – Page 655.
3. W K V Gale. The Black Country Iron Industry, 1966 – Page 130.

BOOK REVIEWS

Alastair Borthwick. Hallside - one hundred years, 1873-1973. British Steel Corp. Special Steels Div., 1973. 24 pp, A4 format.

This is the history of a Clydeside steelworks that had the distinction of making the first steel in Scotland which was used in ships and the Forth railway bridge, one of the earliest large structures to be made in steel. It was founded by Charles Tennant who sought to use the plant to recover the iron from "Blue Billy", the ferruginous by-product of sulphuric acid-making from Spanish pyrites. Although Blue Billy was not used for steel making, Siemens was consulted from the start, and the works became one of the first to make steel by the Siemens open hearth process just at the time when steel was beginning to replace wrought iron in ships. The author does not unfortunately tell us why Blue Billy was found to be unsuitable but presumably this was due to its high residual sulphur content; the plant had no iron-making equipment. But in 1874, two Siemens revolving furnaces were erected for the direct reduction of the Blue Billy but this process proved too costly and was abandoned in 1875. In 1878, James Riley, one of the earliest researchers into nickel alloy steels, became its general manager.

In its 100 years the plant, which started with four 6 ton producer gas fired open hearth furnaces, became after many vicissitudes part of the Colvilles group in 1936, and then part of the BSC upon nationalisation in 1967. Today it has an output of over 3000 tons/week using a single 100 ton electric arc furnace to produce alloy steel billets.

R.F. Tylecote

P.J.Riden. The Butterley Company, 1790-1830 *(published by the author, and available from 18, Mill Lane, Wingerworth, Derbyshire)* 1973, 61 pp. £1.00.

This short history of a Derbyshire mining and foundry concern was first written as an undergraduate dissertation, and is intended to be the first part of a study of the Butterley Company up to the time of its reorganisation in 1947. The original essay has been recast, and produced in offset-litho, unfortunately involving many errors in proof reading, few of which are corrected on the sheet which accompanies the book. Nevertheless a great deal of work has gone into the research and writing; the references are commendably full, in effect providing a guide to the earlier Butterley records in the Derbyshire Record Office at Matlock, and indeed the whole book is avaluable quarry of original material for further synthesis.

There are four main chapters, dealing with the creation and structure of the partnership, the physical and technical development of the works, its organisation, both of production and labour, and, finally, the markets and access to them. There is a tendency in each case to take the available material chronologically and, particularly in the first chapter, the main themes stand out less clearly than they might. A particular problem is the minor place, a part of the last chapter, given to the products of the company. Many readers will ask at the outset what it produced, and how successfully it catered for its market, but this rationale for its existence is rather concealed behind the detailed conduct of affairs. However, we have here a valuable approach to the history of a firm which has an important place in the early-nineteenth century development of foundry production, well attested by products such as its steam engines or the surviving structural ironwork that bears its name. It makes worthwhile, if rather dry reading.

University of Sheffield. *D. W. Crossley*

The production of steel in Britain by the cementation and crucible processes

K C Barraclough

Considering the importance of the cementation and crucible processes in the history of steelmaking in general and in the development of the Sheffield area as the centre of the "special" steelmaking trade, it is a matter of supreme interest to endeavour to determine the scale of operations. This is known only in vague terms by tradition and by reference to contemporary estimates but there are no absolute statistics over any period of the production; on the contrary, it seems to have been the aim to maintain a veil of secrecy. Moreover, for the last fifty to sixty years of the active life of the processes even the sparse published references fail us. It is fascinating, therefore, to try piecing together such details as might lead to a continuing picture and the argument that follows is one attempt in that direction. It is realised very clearly that there are many pitfalls and that rule of thumb computations on very limited evidence and subjective interpretations may undoubtedly lead to grossly erroneous conclusions. Nevertheless, it has been considered worth advancing this theoretical treatment of the subject; it may well provoke fruitful discussion; it may lead to the revealing of sources of information not known to the author and a more accurate assessment may be made possible.

The earliest figure yet discovered for an estimate of Sheffield steel production comes from the evidence given by Wm. Vickers to the Select Committee on the Sheffield and Rotherham Railway Bill in 1835[1]. He quoted an annual output of 12,000 tons of cementation steel *(a figure later confirmed by S.Jackson[2] in the same context)*, 9,000 tons of this subsequently being remelted in crucibles. This was produced from 10,000 tons of imported Swedish and Russian iron, 1,000 tons of English iron *(for the manufacture of springs)* and 1,000 tons of scrap of both iron and steel.

This also appears to be the source of the information given by Porter[3] who also stated that there were in Sheffield at this time some 56 converting furnaces and 62 melting shops with a total of 554 melting holes.

The next evidence is that of Le Play. He reported that in 1837 the production of cementation steel in South Yorkshire was 180,000 metric quintals *(just under 18,000 tons)* but that the level of production had fallen so that the average production over the period 1836 to 1842 had been 16,250 tons per annum[4]. At the same time the various steelworks near London, in Staffordshire, in Somerset and in Lancashire had delivered about 4,000 tons per annum of raw cement steel. The raw materials came mainly from Sweden *(63%)* and Russia *(22%)*; some 2% came from Norway and the remaining 13% was home produced iron.

He reported 33 works with a total of 97 cementation furnaces[5] and implied that they should have been able to give almost twice the output actually realised had there not been a state of recession in the steel business in Yorkshire over this period. He elsewhere stated that the the 51 steel melting shops, despite trade stagnation in 1842, converted some 165 tons of blister steel per week into cast steel, some 52% of the output of the cementation furnaces[6]. He later gave the number of melting holes as 774[7]

E.G.Danielsson, in his report on a journey to England and America in 1843[8] gave the consumption of imported iron in steelmaking in this country as 64% Swedish, 3% Norwegian and 33% Russian; the Swedish import was 92,000 skeppund *(12,400 tons)*. In addition, 15,000 skeppund *(2,000 tons)* of iron from Low Moor, Bowling and Milton were used in the Yorkshire steelworks; from these figures a cementation steel production of 21,400 tons can be deduced, which agrees closely with Le Play's figure for a year earlier.

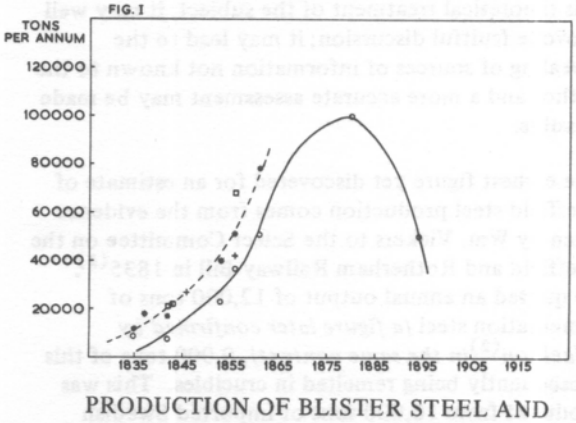
Evidence for 1846 comes indirectly via the Swedish sources but has its origin in the evidence by Henry Unwin a Sheffield importer of Swedish iron, to a further Select Committee on a Railway Bill for the Sheffield area. The original is still being sought but reference to it was made in a motion put to the Riksdag in Stockholm in 1853/4 by C. F. Waern, a well known Swedish businessman and exporter if iron to England[9]. A portion of this report was quoted by Scrivenor[10]; his translation of the passage is apparently correct *(even to the misquotation of Porter's estimate for 1835 as 15,000 rather than 12,000 tons)*; from it we learn that in 1846 the number of converting furnaces in Sheffield had increased to 105 and the melting furnaces to 974, giving an estimated output of 26,250 tons of cementation steel. Incidentally Waern also quotes Gustav Ekman having reported in 1845 that the amount of home produced iron used in Sheffield had risen to 3,000 tons.

Waern also quoted the recent evidence for 1853, this again being derived from Unwin who had been requested to make a special survey in the July of that year. If the correspondence on this occasion could now be discovered it would indeed be a valuable document, since Unwin, in an attempt to be fully factual, listed the cementation furnaces in Sheffield by owner and situation. Waern's business papers have been lodged with the Gothenburg Archives but no trace of this letter has yet been found. There were, however, 160 cementation furnaces and 1495 melting holes in Sheffield at this time, giving an estimated production of 40,000 tons of cementation steel; consumption of home produced iron was reported to have risen to 7,200 tons. On this topic it is stated that "the English steel iron is well known for its density *(not "closeness" as stated by Scrivenor)* and purity and some of the best marks are so much in demand that they sell at a higher price than most of the Swedish grades. No wonder the Swedish manufacturer is worried!" *(This last sentence does not appear in Scrivenor).* Sanderson, commenting on these figures in 1855[11] suggested that the amount remelted in crucible at this time was 23,000 tons per annum.

Hunter[12] dealt with the situation in 1856 and indicated 206 cementation furnaces and 2113 melting holes in Sheffield in that year. The estimated production of cementation steel in Sheffield was 51,500 tons; there were 54 similar furnaces in other parts of the country producing 13,500 tons between them. *(It should be noted that these figures all assume a production of 250 tons per furnace per annum).* There is also to be found in Hunter the significant statement that 3,000 tons of steel was made direct from iron in the melting furnaces without going through the converting furnaces. This gave an overall total for British steel production in 1856 of 68,000 tons. The 2113 melting holes in Sheffield were quoted as producing 37,834 tons and 245 holes elsewhere in the country would have made 4,410 tons *(at a rate here of 18 tons per furnace per annum, allowing for a slight miscalculation on the Sheffield production).* So, the total cast steel output for the country was just over 42,000 tons.

The same source[13] also gives evidence for 1862. Strangely enough, the number of cementation furnaces had fallen from 206 to 205; the size had presumably increased, however, since the cementation steel output was quoted as 78,270 tons *(384 tons per annum per furnace).* The number of steel melting holes had, however, risen to 2437 *(now over 21 tons per furnace per annum)* giving a total of 51,616 tons of saleable cast steel. It is not clear from the text whether this refers to Sheffield or to the country as a whole; since the history is one of Sheffield, the former seems to be indicated.

After this date, steel began to be considered more and more as the product of the bulk processes. The Bessemer-Mushet process produced 300,000 tons in 1871 and over a million tons in 1880; the Siemens-Martin process gave similar tonnages about 8-10 years further along the time scale. Official statistics for steel production begin on a continuous basis from 1868 onwards but cover these two processes only *(with their acid and basic variants later)* and give no figures whatsoever for cementation or crucible steel. The only indications we have, in fact, of the special "Sheffield methods" as they were called at this time, is a tradition so oft repeated that it must have some foundation, to the effect that the peak production of crucible steel was around 100,000 tons in around 1880 and the statement made by Robert Hadfield in 1894[14] to the effect that 14,000 crucibles were still used weekly in Sheffield. This implies two things: firstly that production had passed its peak; secondly that, assuming the 60 lb. crucible to be in general use at that time and to be used three times before discarding, the output of crucible steel in 1894 was just over 50,000 tons. The information we have so far gleaned can be plotted[Figure 1]. The picture so derived is almost a classical case of development, maturity decline and obsolescence, the latter giving a terminal date of around 1900. But this is too simple to be true; there were substantial imports of Swedish iron into Sheffield right up to and during the First World War. Moreover, it is known that the peak production of crucible steel in America, in France and in Germany was in the period 1916-17[15]. Let us then attempt to derive other evidence of the level of production across the years.



PRODUCTION OF BLISTER STEEL AND CRUCIBLE STEEL AS GIVEN IN THE LITERATURE *(See text for details)*

○ CRUCIBLE STEEL – SHEFFIELD
+ CRUCIBLE STEEL – TOTAL
★ BLISTER STEEL – SHEFFIELD
□ BLISTER STEEL – TOTAL

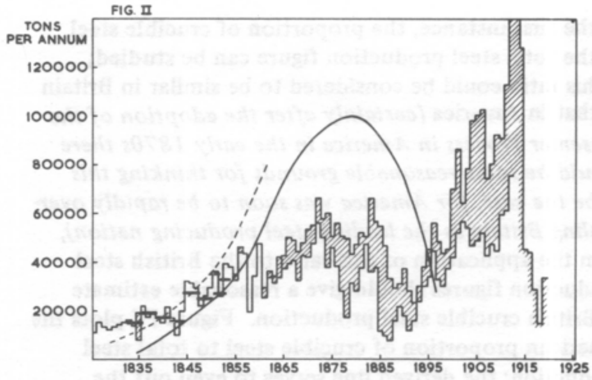
The first line of approach is to study the flow of Swedish *(and Russian)* iron into this country, since these formed in any case a major item in the furnace charges. Certainly from around 1800 onwards, the import of foreign iron into Britain was mainly for steel production: the domestic supply of wrought iron had by this time reached a sufficiently high level for all ordinary requirements to be met in this way, particularly as its price had for all time fallen below that of the imported iron at the turn of the century and Britain was to become the major producer of this commodity for the next seventy or eighty years. Thus, although when 959 tons of bar iron came down the canal from Hull to the Sheffield area in a twelve month period from 1771 to 1772 *(as can be derived from the Hull Water Bailiff's records)* some of this was undoubtedly for normal blacksmith's needs as well as to supply the rising Sheffield steel industry, the estimated 3,000 tons which was anticipated as being part of the annual freight from Tinsley into Sheffield at the time of the canal survey in 1802 would almost certainly be a fair measure of the output of the Sheffield cementation furnaces at that time.

From this date until about 1850, the import of iron from Sweden and Russia can be expected to give fair indication of the growth of steelmaking activity, although, as we have seen, there was a growing if minor use of home produced iron for cementation.

The imports of iron into this country can be assessed in various ways. Fortunately, the official records both in this country and in Sweden have been examined by other workers. In the first place, there are figures for total bar imports into this country, together with the details of re-exports, as summarised by Mitchell and Deane[16]; the difference between these two figures, indicating the consumption in this country, can be plotted annually for the whole of our period. On the other hand, from enormously painstaking researches of Attman[17] the figures for Swedish plus Russian bar iron imports into this country, less the re-exports of Swedish iron, can be plotted from 1815 to 1900 *(the Russian contribution is relatively insignificant after 1860).* From 1901 to 1912 the same source gives the Swedish bar iron imports less re-exports through Hull and London only. These figures have been plotted in Figure II, with the two lines from Figure I superimposed. The figures show a reasonable correlation between the two up to about 1855; thereafter we need another argument.

We know that iron was puddled in Sheffield, presumably using mainly home produced pig iron, from 1858 onwards. We also know that, in increasing measure, from 1850 onwards *(as indeed had been indicated by Hunter in his survey of the position in 1856)* crucible steel was produced from bar iron without cementation, by melting it with the appropriate proportion of Swedish white cast iron *(or even alone with charcoal);* in fact, the River Don works, established in 1862 and then the largest and best equipped of its kind in the world, was built without any cementation furnaces whatever, but with 384 double crucible holes, with an annual capability of almost 15,000 tons. The owners, Naylor, Vickers and Company, had used puddled steel in their crucibles in 1858[18] at their earlier works in Sheffield. Bessemer, whether with justification or merely in spite

FIG. II



BAR IRON IMPORTS

The upper line represents total bar iron import less re-export *(Mitchell & Deane).*

The lower line represents Swedish plus Russian bar iron import less re-export *(Attman).*

The short horizontal lines from 1832 to 1835 are the figures due to Waern.

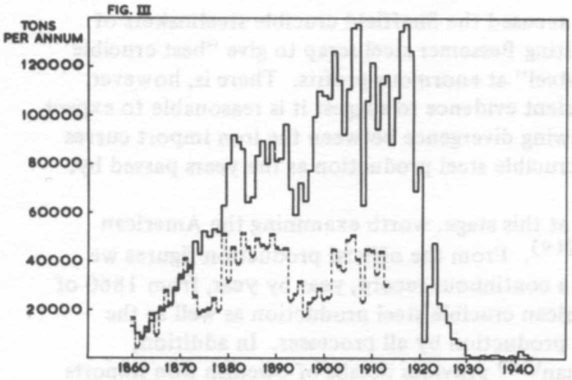
The lines from Figure I are superimposed for reference.

later accused the Sheffield crucible steelmakers of remelting Bessemer steel scrap to give "best crucible cast steel" at enormous profits. There is, however, sufficient evidence to suggest it is reasonable to expect a growing divergence between the iron import curves and crucible steel production as the years passed by.

It is, at this stage, worth examining the American data[19]. From the official production figures we have a continuous record, year by year, from 1860 of American crucible steel production as well as the total production by all processes. In addition, Attman[20] provides details of Swedish iron imports into America up to 1913. The two sets of figures can thus be directly compared. It has to be remembered that crucible steel manufacture in America only really gathered momentum after about 1850 and thus the growth period is covered by these statistics, which can be found plotted together in Figure III. From this, it will be seen that there is relatively good correlation in these early years *(up to 1872)* between crucible steel production and bar iron import. The parallel with Figure II, in fact, is striking and it is of particular interest to note the time lag of 15 years or so between the two countries. Beyond 1872, however, as beyond 1855 in this country, there is a rapid divergence between the curves. This American data is of value in other ways, since it can be utilised to provide estimates of British crucible steel production; their absolute validity can be called into question but nevertheless they are worthy of consideration.

In the first instance, the proportion of crucible steel to the total steel production figure can be studied; if this ratio could be considered to be similar in Britain to that in America *(certainly after the adoption of the Bessemer Process in America in the early 1870s there should be some reasonable grounds for thinking this to be the case, for America was soon to be rapidly overhauling Britain as the leading steel producing nation),* then the application of this ratio to the British steel production figures should give a reasonable estimate of British crucible steel production. Figure IV plots the American proportion of crucible steel to total steel production; the derived line serves to even out the vagaries in the individual annual figures to produce the trend. If the figures derived from this line are then applied to the British annual production figures we then arrive at the position shown in Figure V, which also carries the line from Figure I for crucible steel production for comparison. There is some correlation between the two, particularly from 1887 to 1895; over the earlier years there are decided deviations, however. It should be remarked in passing that the traditional figure for 1880 and the Hadfield figure for 1894 fit both plots.

FIG. III

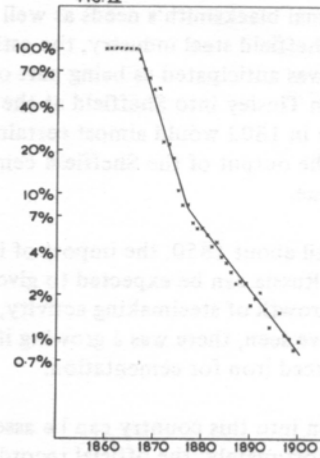


AMERICAN CRUCIBLE STEEL PRODUCTION
(taken from A.I.S.I. Statistics)

The American import of Swedish bar iron is shown as a dotted line.

The second manner which the information can be utilised is to consider the degree of consumption of the Swedish bar iron import in the American crucible steel production. Figure VI shows the proportion of bar iron to total production and appears to indicate four distinct periods after departure from the 100% use up to 1872. For the next ten years there is an average usage of 43%; despite various departures from this figure, the mean usage over the 42 years period from 1872 to 1913 is of the same order. If this figure were to be considered relevant to the British production also, and we apply this to the import of Swedish plus Russian iron less re-export from 1857 onwards, using the Attman figures, we arrive at the position shown in Figure VII.

FIG. IV

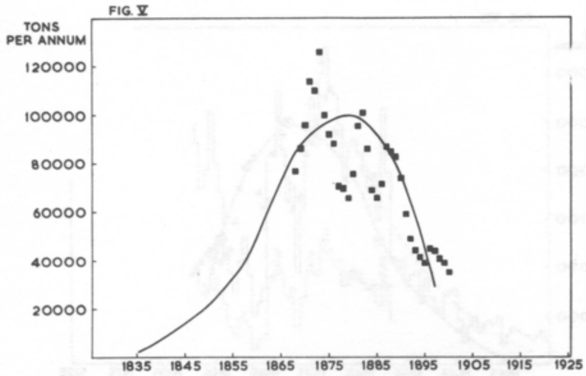


AMERICAN CRUCIBLE STEEL PRODUCTION
(expressed as the proportion of crucible steel to total steel production)

This curve shows reasonable agreement with the curve for cementation steel production derived from Figure I over the earlier years; the 1880 and 1894 points are satisfied. The really fascinating feature, however, is the manner in which the points derived from the American ratio applied to British steelmaking correlate with this curve derived from the bar iron imports over the period from 1868 to 1885. Another important feature is the manner in which the import figures show the effect of the various trade booms and depressions in the notorious 1873 to 1896 period. This is much more credible than the smoothly rising and falling curve from Figure I. Moreover, the rise in production beyond 1893 is in keeping with the other evidence.

One point requiring clarification at this stage is that earlier reference has been to the correlation between the bar iron import and cementation steel production, whereas we are now relating it to crucible steel production. As far as can now be determined, little or no building of cementation furnaces occurred after 1860. As has already been stated, the River Don works in 1862 was built without cementation facilities. The cementation furnaces at the larger establishments, such as Cammells, Firths and Browns, appear to have been reduced in numbers over the years and eventually only the steel destined for machine tools and high grade cutlery was made by the remelting of cementation steel; later still, even this type of production came to rely on other means except at the smaller works. In addition, the production of shear steel from the cementation steel by forging declined. The assessment of the magnitude of the production of cementation steel after 1861 is therefore even more nebulous than that of crucible steel.

FIG. V



ESTIMATE OF BRITISH CRUCIBLE STEEL PRODUCTION

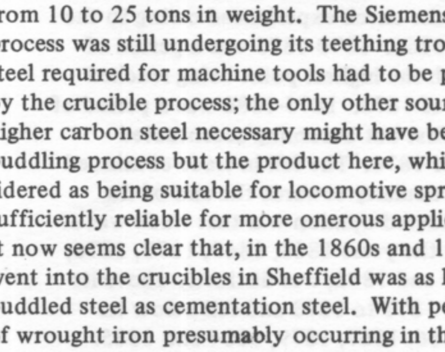
The black squares are derived by applying the percentage values from Figure IV to the total British steel production.

The superimposed curve is the crucible steel production from Figure I.

Up to this time more cementation steel had been made than crucible steel; it is likely, however, that the cementation steel figures thereafter tended to remain static for some period of time and then to decrease at a time when the crucible steel production was still rising. From this time onwards, therefore, the total production by "Sheffield methods" would be measured, not by the amount of bar put through the cementation furnaces, but by the output of the crucible furnaces plus the diminishing amount of cementation steel which was forged direct without remelting. From around 1865 or so, therefore, our argument shifts to the production of crucible steel. The Hunter figure of just under 80,000 tons for cementation steel in 1861 could well be more or less the peak output for this process.

The growth of crucible steel melting capacity cannot be measured any longer in terms of the number of furnaces either. We know the River Don works in 1862 added 15,000 tons annual capacity; we know the introduction of the Siemens regenerative type of furnace gave multiplication of the number of crucibles per hole – as many as twelve crucibles per chamber was current in 1920; we know that the size of crucible was increasing – records from the late 1850s and early 1860s indicate the use of 40 lb. crucibles whereas in the late 1870s the 60 lb. crucible was standard and appears to have remained so thereafter. What can be said, therefore, concerning the peak output figure shown in Figure VII for 1871 to 1872? In the first instance, if we produce the cementation curve upwards it would give a figure of around 150,000 tons in 1872. The demand for steel was certainly rising sharply and the period in question was one of marked prosperity; it is the period from 1873 to 1896 which the economic historians consider as the time of disturbance. The Bessemer Process had by then survived its trials and was producing material which satisfied engineering needs; in the main, however, it was superseding wrought iron. It was still felt necessary to use the crucible process for any important application for steel; witness the multiple casting operations to produce forging ingots from 10 to 25 tons in weight. The Siemens open hearth process was still undergoing its teething troubles. The steel required for machine tools had to be produced by the crucible process; the only other source of the higher carbon steel necessary might have been the puddling process but the product here, whilst considered as being suitable for locomotive springs, was not sufficiently reliable for more onerous applications. It now seems clear that, in the 1860s and 1870s, what went into the crucibles in Sheffield was as likely to be puddled steel as cementation steel. With peak production of wrought iron presumably occurring in the period, the need for cutting tools would also be at a high level. Nevertheless tradition would cast some doubt on the validity of a figure of 130,000 to 140,000 tons of crucible steel at this period; the degree of coincidence between the two sets of derived figures and the total shape of the curve from 1825 onwards, however, does give some plausibility to such a conclusion. To accept this figure as credible does, it is true, involve more than a doubling of furnace capacity in 10 years; on the other hand, the late 1860s must have been a period of considerable optimism and the Sheffield steelmakers have always

FIG. VI



USAGE OF SWEDISH BAR IRON IN AMERICAN CRUCIBLE STEEL PRODUCTION

The percentage ratio of bar iron import to total crucible steel output plotted against date. There appear to be four groups:

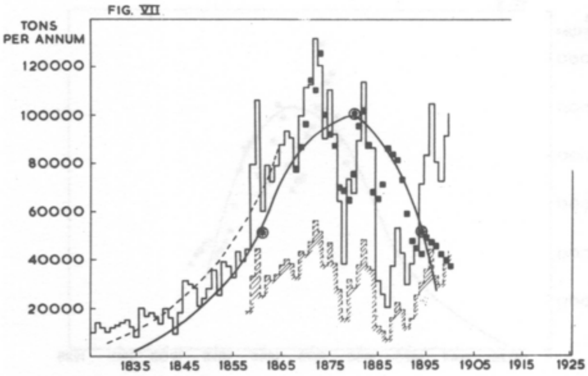
Period	Mean Ratio
1872–1882	43.4%
1883–1895	54.5%
1896–1901	26.0%
1902–1913	36.7%
OVERALL	42.4%

been quite ready to take advantage of the demand and to attempt to meet its needs.

In this context, the comments of the representatives of the Sheffield Chamber of Commerce to the Royal Commission on Depression of Trade and Industry in 1885 are of interest[21]. There it was stated that 1865-1870 was a period of steady and progressive business, save for the check experienced owing to the financial crisis of 1866. 1870-1875 was a period of great inflation with the highest point being reached about the middle of 1873. 1875-1880 was a period of reaction, slow at first but becoming accentuated towards the end of 1878. The fall in trade continued in 1880-1885, particularly towards the end of the period. The considered opinion was that trade was at its normal level in the years 1868, 1869, 1870, 1876, 1877, 1880, 1881 and 1882, was distinctly above its normal level from 1871 to 1873 and fell below its normal level in 1866, 1867, 1879, 1884 and 1885. The pattern in Figure VII is not inconsistent with this general impression. The figures for 1858 to 1860 and the depths of the depressions from 1884 to 1893 do, however, appear to call for some discussion and the period from 1895 onwards obviously requires further consideration.

In the first instance we have the break away from imported iron; from 1830, if not before, imported iron had gradually ceased to be the sole part of the furnace charge and the apparent coincident import of iron and output of steel owes much to the incompleteness of the evidence; in actual fact the gap is showing from 1852 onwards and it is to be remembered that the curve plotted is for Sheffield production only whilst the imports are for the whole country – this gives a discrepancy of around 20% as we have already noted for 1856, but this should decrease substantially over the next twenty years. The percentage of imported iron in the furnace charges would appear to have declined progressively from around 1850 as the newer ideas became more generally accepted; it would not be a sudden drop to the figure of 42% previously postulated. On consideration, it seems reasonable to apply a figure of 80% from 1852 to 1855, 65% from 1856 to 1860 and then 42% from 1861 onwards; this obviously is a purely arbitrary selection of ratios. The effect can be seen in Figure VIII; with the exception of a deep trough around 1858 the results do, however, appear to fit the curve derived from the literature evidence reasonably well.

With regard to the later discrepancy noted above, there is a trend in America towards a higher use of the imported Swedish iron in the period from 1883 to 1895; this could be a reflection of the differing situation after full



PRODUCTION OF CRUCIBLE STEEL IN BRITAIN BASED ON SWEDISH BAR IRON IMPORT

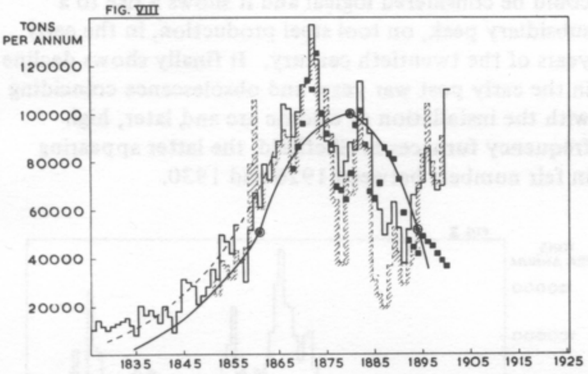
PRIOR TO 1858: Full stepped line represents Swedish plus Russian bar import less re-export *(Figures due to Attman).*

FROM 1858 TO 1900: Full stepped line represents bar import less re-export itself.

Asterisks are individual figures for crucible steel production from the literature; the full curve is the crucible production as derived in Figure I, the dotted curve being the comparable one for cementation production. Square symbols indicate estimated crucible steel production derived from consideration of the American data as in Figure V.

establishment of the bulk steelmaking processes in that the crucible steel production was being restricted more and more to the specialist uses where the quality of the iron could be reflected in the quality of the final product. Comparison with Britain is interesting; in the first instance, we must remember that Britain was originally several years ahead of America, but this lead must be considered as being reduced as the years passed by; by 1890 it must have gone. On the other hand, probably on geographical grounds, it seems that the bulk of the iron imported into America was Swedish, whilst the discrepancy between the British figures for total iron import less re-export and the comparable figures for Swedish and Russian iron indicates a different situation. In the twentieth century, it is known that some iron, notably from American haematite sources, was imported and used as a small part of the needs of the peculiarly British insistence on Acid Open Hearth steel at a time when the rest of the world was making more and more use of basic steel *(in 1901 only 17% of the total production of 5 million tons was in basic steel).* This might well explain the divergence between the two curves shown in Figure II at this later stage, but it certainly did not in 1860 and for some years afterwards. If we try to follow the pattern of a minimum usage of imported iron from 1861 to say 1875 and then a rise to somewhat higher proportion for the next twenty years, we find that, if we apply this to the total import rather than the Swedish plus Russian only and use figures of 50% for the earlier period and 60% for the later period, again purely arbitrary figures, we arrive at the situation shown in Figure VIII, which shows some divergence from the pattern shown in Figure VII; in the main, however, it confirms the peaks and reduces the depths of the troughs. It is felt that, in times of stringency, the initial action would be to cut off the more expensive supplies of Swedish iron rather than cut down on the locally produced material or the cheaper imports and thus the use of the Swedish imports alone for our assessment could well intensify the effect of the slump in demand. For this reason, the position shown in Figure VIII is preferred, at any rate up to 1895.

FIG. VIII



MODIFIED PLOT OF CRUCIBLE STEEL PRODUCTION USING TOTAL BAR IRON IMPORT LESS RE-EXPORT

Full stepped line derived as follows from total bar iron import less re-export:

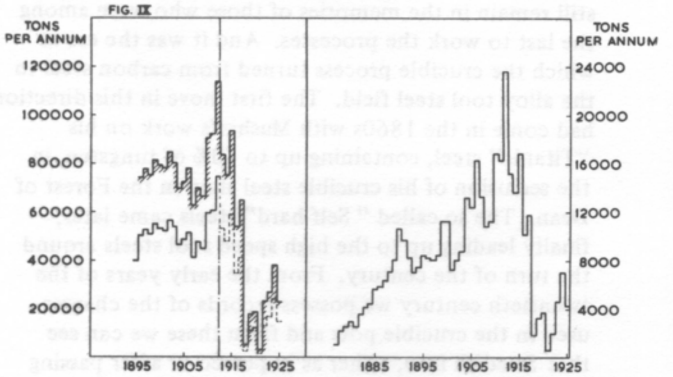
TO 1851 x 100/100
1852–1855 x 100/80
1856–1860 x 100/65
1861–1875 x 100/50
1876–1895 x 100/60

Dotted shaded line represents the plot from Figure VII; other data as in Figure VII.

The correlation with the American ratio data is still no better after 1885; this particular argument therefore has to be considered as being useful in the period of 1868 to 1885 as confirmatory of the argument based on imports but thereafter must be discarded, incidentally indicating a change in pattern between British and American practice after this date.

We now have to consider the period from 1895 onwards. There is a complete lack of easily accessible data here; the last reference so far found dates from 1894. On the other hand, this is the period traditions of which still remain in the memories of those who were among the last to work the processes. And it was the era in which the crucible process turned from carbon steel to the alloy tool steel field. The first move in this direction had come in the 1860s with Mushet's work on his "Titanic" steel, containing up to 10% of tungsten, in the seclusion of his crucible steel shop in the Forest of Dean. The so called "Self hard" steels came later, finally leading up to the high speed tool steels around the turn of the century. From the early years of the twentieth century we possess records of the charges used in the crucible pots and from these we can see that Swedish iron, either as imported or after passing through the cementation furnace, together with Swedish white iron or charcoal and the necessary alloying elements gave the charges for these important materials which, at that time, could only be produced by the crucible process. One of these records selected virtually at random gives the charges for almost 2000 melts in 1902 to 1903 made by Daniel Doncaster and Sons; this shows an overall average usage of 64% of imported Swedish iron. A similar but less complete record from Wm. Jessop & Sons in 1910 shows a similar picture with around 60% utilisation; isolated information elsewhere gives a figure of 55-70% although it must be stated here that the most recent information from the period 1930 to 1945 shows the figure to have decreased to around 40%, the balance being provided from scrap, which was much more sparingly used earlier – possibly due to an expanding market? To apply this argument to attempt to derive a production figure we have specifically mentioned Swedish imports. These figures are not easily come by and it has been thought fit to derive our background data here from the curves published by Attman[22]. Here we can find plots for the import of Swedish iron through Hull and London, less re-exports; by combining these we can get a figure for home consumption which may be somewhat on the low side since there may have been imports elsewhere: through the Tyne, for instance. It is significant, however, that the proportion through London becomes relatively small during this period of 1895 to 1912. After 1912, the Attman figures fail us; we have, however, the local records of imports through Daniel Doncaster and Sons and, as will be seen from Figure IX, they represent some 28% of the total import through London and Hull for the period of 1904 to 1912; it is not unreasonable, therefore, to feel that these figures beyond 1912 can be used to indicate the trend in production[23]. Therefore, assuming that from 1895 to 1925 we have a figure for the vital consumption of Swedish iron in this way, by assuming that this represents some 64% of the crucible charges we can arrive at an estimate of the production over this period, which is also plotted in Figure IX.

FIG. IX



CRUCIBLE STEEL PRODUCTION ESTIMATES 1895–1925

RIGHT: Swedish imports to Sheffield via Daniel Doncaster and Sons.

A comparison of these figures with the total import less re-export given by Attman up to 1912 gives the following picture *(all figures in thousands of tons)*:

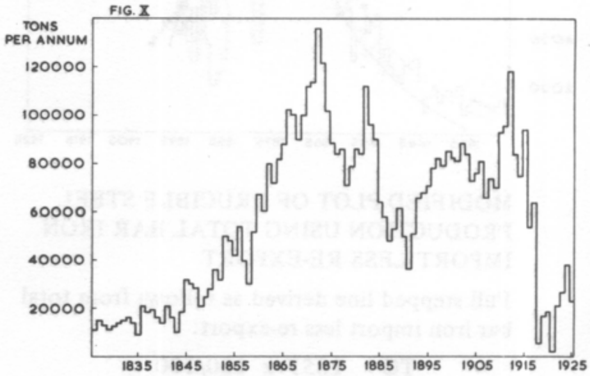
	Doncaster	Attman	Ratio
1904–1906	41.6	147.2	28.3%
1907–1909	38.7	134.4	28.8%
1910–1912	54.6	196.6	27.8%
1904–1912	134.9	478.2	28.2%

LEFT: To 1912: Full unshaded line gives import less re-export figures from Attman. After 1912 dotted line gives estimate of this derived from Doncaster import x 100/28.

The full shaded line is the production derived from both these values x 100/64.

We have thus pieced together in a somewhat arbitrary fashion a plausible argument for possible pattern of production of steel by the traditional "Sheffield methods" of cementation and crucible steel melting. The overall picture can be seen in Figure X. The whole matter is obviously one of subjective analysis in obtaining what can only be described as one observer's assessment of the likely ebb and flow of production over a century in which remarkable changes overtook the steel industry as a whole and in which, as far as the subject under discussion is concerned, not one single official figure for production by these methods exists. For want of a better, however, this assessment is put forward as a not improbable production history of a process which at the beginning of the period was the sole source of British steel and which laid the foundation of the alloy steel trade in Sheffield. Realising that most of the argument is derived from the import data and also that the imports from one year may well be stockpiled to give production material the following year, the same information has been replotted in Figure XI on a three year average basis, together with the curves derived from the literature and it is in this form that the data should finally be presented. The information from the American ratio data for 1868 to 1885 is also shown. The pattern is thus of peak production in the boom period of the 1870s, rather than during the First World War, which seems to have been the case elsewhere; this is, however, not unreasonable in the country of the origin of the Huntsman Process. The foreign competition at this time was still inconsiderable, except possible from Essen, and exports were running at a high level; at this time, in addition, ingots for large forgings were still being produced by multiple casting from crucibles. The curve also shows the effect of the depressions of the 1870s and 1889s in a manner which could be considered logical and it shows a rise to a subsidiary peak, on tool steel production, in the early years of the twentieth century. It finally shows decline in the early post war years and obsolescence coinciding with the installation of electric arc and, later, high frequency furnaces in Sheffield, the latter appearing in fair numbers between 1926 and 1930.

FIG. X



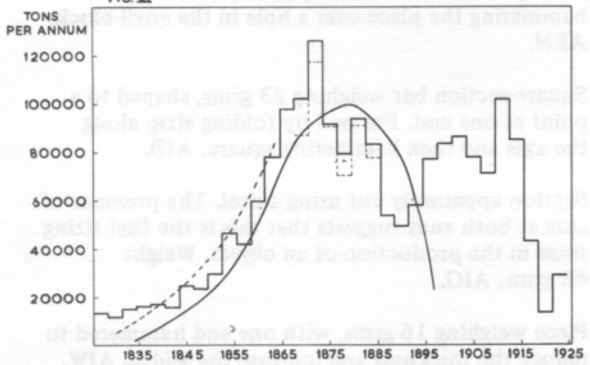
FULLY DERIVED NOTIONAL PLOT FOR BLISTER AND CRUCIBLE STEEL PRODUCTION IN BRITAIN

Up to around 1862–5 this represents the estimated blister steel production, an increasing quantity of which was remelted in crucibles. From this time onwards it represents crucible steel production plus the small amount of blister steel not remelted in crucibles.

A final point of interest is to be derived from Figure XI. If our reasoning is correct, the proportion of crucible steel to total British output remained at between 1%

and 2% from 1886 to 1915; this is a far larger proportion than in America over the same period. In absolute terms, the production of crucible steel was of the same order in both countries according to this assessment whilst the American steel production in total rose from being roughly equivalent to the British tonnage in 1886 to more than four times the British production in 1915. This relatively steady production ratio in Britain is logical if the crucible furnaces were providing the essential tools for the engineering industry and it is only with the rise of alternative means of production of such steels that the ratio fell in the last decade of our survey.

FIG. XI



NOTIONAL PLOT BASED ON THREE YEAR AVERAGES

This is derived from Figure X.

The curves from Figure I are included for comparison.

The dotted lines from 1867 to 1885 are estimates based on Figure V (applying American ratio to British total production).

REFERENCES

1 Minutes of Evidence to the Lords Committee on the Sheffield to Rotherham Railway, 1835, p.11.

2 Ibid, p.34.

3 G R Porter, "The Progress of the Nation", Revised edition, ed. Hurst, 1910, pp.240-1.

4 F le Play, "Memoire sur la Fabrication de l'Acier en Yorkshire", Annales des Mines, 4me. Serie, Tome III, 1843, p.687.

5 Ibid, p.621.

6 Ibid, p.640.

7 Ibid, p.692.

8 E G Danielsson, "Anteckningar om Norra Amerikas Fri-Staters", Stockholm 1845, pp.32-33.

9 C F Waern, "Om Jerntillverkningningen och Jernhandeln"; Riksdags Bilaga, 1853-4, pp.49/50.

10 H Scrivenor, "History of the Iron Trade", 2nd ed, 1854, pp.155-6.

11 G Sanderson, "On the Manufacture of Steel, as carried on in this and other countries", Journal Society of Arts, Vol 3, 1854-5, p.458.

12 J Hunter, "The History and Topography of the Parish of Sheffield in the County of York", edited Gatty, 1869, p.214.

13 Ibid, p.216

14 R A Hadfield, J.I.S.I., 1894, Vol 2, p.234.

15 The American data comes from the official A.I.S.I. statistics *(See Figure III: the value for 1916 just exceeds that in 1907).* The German and French information can be found in the Diamond Jubilee issue of the Iron & Coal Trades Review, Dec.1927, pp.211 and 215. For both countries peak production was in 1917 *(130,000 Tons in Germany and 40,000 Tons in France).*

16 B R Mitchell and P Deane, "Abstract of British Historical Statistics", 1962, p.141.

17 A Attman, "Fagerstabrukens Historia: Adertonhundratalet", Uppsala, 1958, Diagram 1 *(p.10)*; Diagram 14 *(p.245)*; Diagram 15 & 16 *(pp.246-7)*.

18 Discussion of paper by Clay in Journal Society of Arts, 1858, p.146.

19 American Iron and Steel Institute Official Statistics. "Steel Production and Index", 1964.

20 A Attman, loc. cit., Diagram 4 *(pp.20-1)*.

21 Second Report of the Royal Commission on Depression of Trade and Industry *(C 4715)*, 1886, p.406.

22 A Attman, loc. cit., Diagrams 15 & 16 *(pp. 246-7)*.

23 These figures are derived from Daniel Doncaster and Sons "Ledger" which covers their contract purchases of Swedish materials from 1869 to 1926. This information and also the opportunity to inspect the charge books is by courtesy of R T Doncaster.

Evidence of iron working at Braughing

The Braughing site is situated to the east of Puckeridge, some 220 yards along road B1368 from its junction with the A 10 *(map reference TL 381236)*. The Roman Ermine street crosses B 1368 at this point, heading north from London.

The material described below was taken from the east ditch of the Roman road revealed by the excavations of 1972 which also provided evidence of adjacent occupation, predominantly 1st cent. A.D. but extending into the 4th.

The excavations were conducted by the Braughing Excavation Committee for the Department of the Environment, and were directed by Mr T Potter. The writer is indebted to him for permission to publish separately this appendix to his site report.

IRONWORKING RESIDUES

Ironworking evidence was recovered from locations AA. AB. AD. AE. AG. AH. AI. AJ. AK. AP. AQ. and AR. A total weight of 20 kgs. of slag was found. Some slag can be classified as resulting from a wood-ash and sand combination but the majority was of high iron content and of metalworking origin. Even for the wood-ash-sand "glass" a temperature in excess of 1000°C is required, so that a high temperature operation is obviously involved. AI with 5 kg, AA with 3.8 kg, and AJ with 3.7 kg were the most prolific locations. Amongst the slags submitted, 13 pieces of metallic iron were found. They are illustrated in the Figure 1 and are described below.

The remaining slags were searched magnetically for metallic iron content, but only magnetite was detected, as confirmed by subsequent sectioning. Magnetic attraction, due to discrete iron particles in a slag envelope could have indicated local smelting activity. None was found, neither was any material detected which could have served as ore for such an operation. The metallic pieces, 1-13, indicate smithing operations. If these had been part of a sequence from ore to finished object, it is reasonable to suppose that the first forging of the raw smelted bloom would have been carried out in the smithing area. It is probable that inefficiency in sorting the smelting product would then have resulted in some slag with reduced particles being found. As none was found it seems likely that the smiths relied on small semi-finished blooms such as 1 and 6 for their raw material, these being obtained by trading.

Excavation has revealed no smelting site but in a field near the assumed line of Stane street, some 1000 yards to the east of the present excavated area, pieces of iron-rich pan have been found which, from the analysis *(below)*, would serve as ore if sufficiently abundant. The material is essentially hydrated iron-oxide with silica inclusions.

Analysis of local iron-pan *(%)*

H_2O	Fe_2O_3	SiO_2	Al_2O_3
11.25	68.8	12.6	2.4

THE METALLIC IRON PIECES

1. Bloom, weighing 102 grms roughly hammered. Probably the first stage after forging the smelted bloom to expel the slag. AJM.
2. Piece hammered to the form of two truncated cones, weighing 54 grms. One end shows a projecting off-centre feature, possibly resulting from hammering the piece over a hole in the anvil-block. ABN.
3. Square-section bar weighing 23 grms, shaped to a point at one end. Formed by folding strip along the axis and then hammering square. AIB.
4. Section apparently cut using chisel. The presence of cuts at both ends suggests that this is the first sizing stage in the production of an object. Weight 46 grms. AIG.
5. Piece weighing 16 grms, with one end hammered to reduce the thickness and increase the width. AIW.
6. Bloom weighing 131 grms roughly hammered as 1 above. One end shows evidence of a chisel cut to part-off. Sectioning shows a generally low carbon-content, but with some random carburisation as indicated in the illustration, probably during re-heating. One end shows remnants of the original "sponge" structure of the raw bloom. AQP.
7. Bloom weighing 46 grms.AHI.
8. Shaped piece weighing 34 grms. One end slightly flattened. AIB.
9. Round bar weighing 15 grms. taper-hammered at one end. AIB.
10. Rough piece weighing 30 grms. AHL.
11. Piece weighing 31 grms. taper-hammered at one end. ADU.
12. Rectangular-section bar, taper-hammered at one end, weighing 37 grms. As with 9 above it appears to be too short for a chisel but there is a suggestion of "mushrooming" at the non-taper end. A chaser for metal decoration is a possibility. AIR.
13. Piece weighing 15 grms, widening and thinning slightly towards one end. Thick end shows that the piece was folded over during working. AIB.

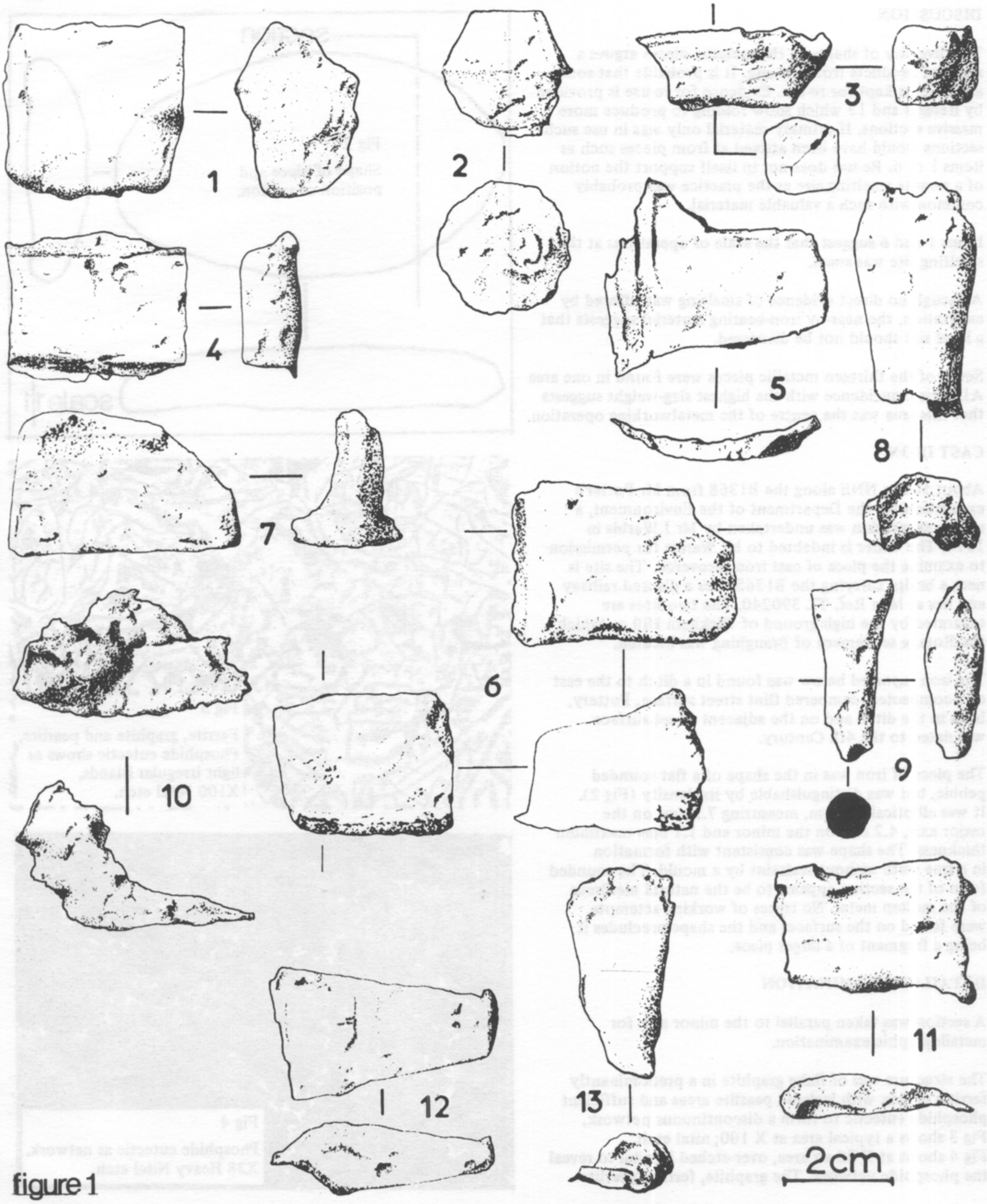


figure 1

DISCUSSION

The diversity of shapes in the metallic pieces argues a range of products from the site. It is probable that some are off-cuts kept for re-use. Evidence for re-use is provided by items 3 and 13 which show folding to produce more massive sections. If primary material only was in use such sections would have been arrived at from pieces such as items 1 or 6. Re-use does not in itself support the notion of a remote smelting site as the practice was probably common with such a valuable material.

Items 1 and 6 suggest that the scale of operations at the smelting site was small.

Although no direct evidence of smelting was offered by excavation, the near-by iron-bearing material suggests that a local site should not be dismissed.

Seven of the thirteen metallic pieces were found in one area A1. This coincidence with the highest slag-weight suggests that this area was the centre of the metalworking operation.

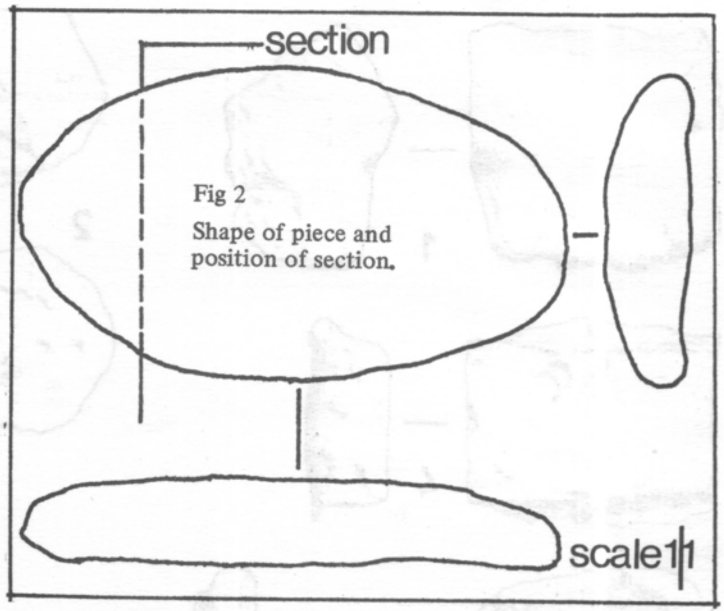


Fig 2
Shape of piece and position of section.

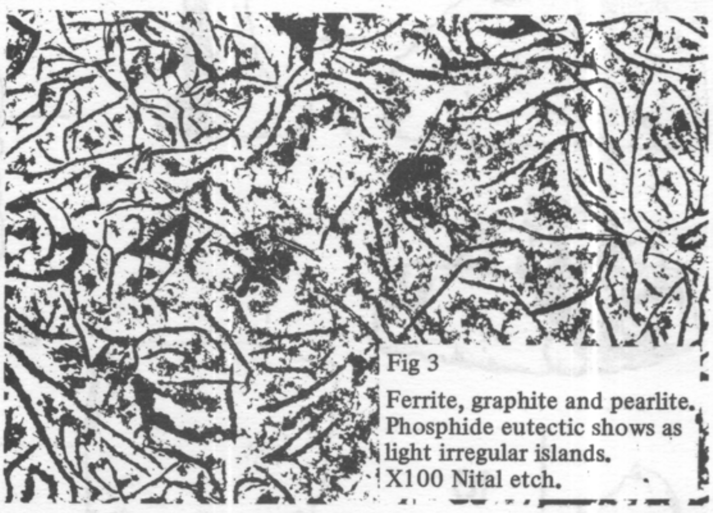


Fig 3
Ferrite, graphite and pearlite. Phosphide eutectic shows as light irregular islands. X100 Nital etch.

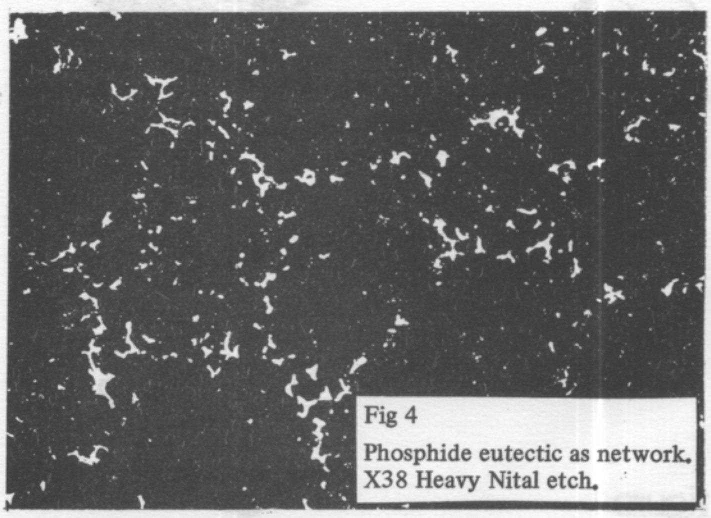


Fig 4
Phosphide eutectic as network. X38 Heavy Nital etch.

CAST IRON

About 500 m NNE along the B1368 from Mr Potter's excavation for the Department of the Environment, a rescue excavation was undertaken by Mr J Warbis in 1974. The writer is indebted to Mr Warbis for permission to examine the piece of cast iron recovered. The site is near a bridge carrying the B1368 over a disused railway and lies at Map Ref. TL 390240. The two sites are separated by the high ground of Wickham Hill on which the Roman settlement of Braughing was located.

The iron reported below was found in a ditch to the east of a compacted, cambered flint street surface. Pottery, both in the ditch and on the adjacent street surface was dated to the 4th Century.

The piece of iron was in the shape of a flat rounded pebble, but was distinguishable by its density (Fig 2). It was elliptical in form, measuring 7.2 cms on the major axis, 4.2 cms on the minor and 1.1 cms maximum thickness. The shape was consistent with formation in a free state without restraint by a mould. The rounded form of the section appears to be the natural meniscus of the molten metal. No traces of working attempts were found on the surfaces and the shape precludes it being a fragment of a larger piece.

DETAILED EXAMINATION

A section was taken parallel to the minor axis for metallographic examination.

The structure was of flake graphite in a predominantly ferritic matrix with isolated pearlite areas and sufficient phosphide eutectic to form a discontinuous network. Fig 3 shows a typical area at X 100; nital etch. Fig 4 shows at X 38 an area, over-etched in nital to reveal the phosphide network. The graphite, ferrite, pearlite relationship was essentially consistent throughout the section with no evidence of chilling.

Hardness tests gave a range from 110 to 119 HV 30 with no obvious trend from "top" through the centre to the "bottom".

Analysis:-

	Braughing	Hengistbury *	Wilderspool *	Tiddington *
Total carbon	3.3%	3.49%	3.23%	3.52%
Silicon	2.62%	0.38%	1.05%	1.92%
Phosphorus	0.26%	0.18%	0.76%	0.77%
Sulphur	0.043%	0.035%	0.49%	0.05%

* See Discussion below.

DISCUSSION

Very few examples of cast-iron from the bloomery period have been reported. Tylecote quotes three in his Metallurgy in Archaeology *(1962)*[1].

Hengistbury Head, Hampshire[2]. 1st Century on page 193 and Table 71.

Wilderspool, Lancashire[3]. 2nd Century on page 244 and Table 80.

Tiddington, Warwickshire[4]. 3rd/4th Century on page 244 and Table 80.

The bloomery, or direct process did not normally achieve a sufficiently long high temperature zone at a high enough carburising potential for the formation of cast-iron. In fact, for a workable product of low carbon, malleable material to result, these conditions must be avoided.

It is safe to assume, therefore, that cast-iron was an accident during this period and due to freak conditions. The almost complete absence of malleability of grey cast-iron makes it totally unsuitable for use by forging techniques.

From –

Liquidus = $1650^{\circ}C - (124{,}5 \times \%\ \text{carbon}) - 26{,}7$ ($\%$ silicon + 2,45 phos.%) a temperature of $1150^{\circ}C$ can be deduced. If a $100^{\circ}C$ superheat, to impart free-running is added, it seems that a temperature of around $1250^{\circ}C$ was involved in the production of this piece. Thus the known bloomery temperature conditions are adequate to produce a molten metal and it is the occurrence of exceptional reducing conditions which produce a composition capable of melting.

The structure, with only traces of pearlite indicates a rate of cooling only slightly faster than is needed to reach the equilibrium ferrite graphite condition. This slow cooling could be achieved within a furnace but the smooth surfaces of the piece seem somewhat inconsistent with this and suggest freezing in an uncluttered area, possibly with a slight slope *(hence the elliptical shape)*. Formation in a furnace bottom would almost certainly leave impressions of the unburnt charcoal and unreduced ore debris associated with this zone. If the iron was tapped or escaped from the furnace with the slag, this could account for the smooth surfaces, the shape and the freedom from oxidation.

The carbon content of the iron/carbon/silicon ternary-eutectic is reduced from 4.3% at zero silicon, by about 0.3% for each 1% silicon. This indicates that a silicon of 2.6% would depress the eutectic carbon to about 3.5%. The 3.3% carbon of the present sample is therefore somewhat hypo-eutectic (−0.2%).

Comparing the three previous cast-iron pieces, the Hengistbury iron at 3.49% carbon is 0.71% below the eutectic 4.2%, the Wilderspool iron is 0.77% below eutectic of 4.0% and the Tiddington iron 0.18% below the eutectic of 3.7%. The similarity between the 4th Century Braughing iron and the 3rd/4th Century Tiddington iron in this respect may have some significance related to the "state of the art" but the number of samples available is obviously too small to do more than observe the relationship.

Conditions would be adjusted in the furnace to avoid making cast iron where ever possible, but the improved efficiency of the later furnaces might be even more likely to produce the occasional high carbon product.

The absence of hammer-marks and the fact that this piece had not been fractured might indicate that the unworkable condition was recognisable by its appearance, or its position in the furnace, alone. This in turn argues that the accidental production of cast iron was not as infrequent as the scarcity of reported evidence indicates.

R C Tribbick

REFERENCES

1. R F Tylecote, Metallurgy in Archaeology, Edward Arnold, London 1962.

2. Bushe Fox, Excavations at Hengistbury Head, Hampshire in 1911-12 Soc.Ants.Report No.3, 1915.

3. T May. Britain's earliest iron furnaces and moulding floors. Iron and Coal Trades Review 1905, 71 Aug.11, 427 et seq.

4. W J Fieldhouse, T May, F C Wellstood. A Romano-British Industrial Settlement near Tiddington, Stratford on Avon, Birmingham 1931.

Letters to the Editor

from Tom Grey Davies

Sir,

I noticed in your Journal *(HMG Bulletin Vol 7/1)* in the article entitled "A note on slag from the first American blast furnace", the statement that the first iron blast furnace in America was erected in the middle 1640s on the River Saugus. This is not quite correct. Iron ore was found in North Carolina by an expedition sent out by Sir Walter Raleigh. In 1619 "John Berkeley with a company of twenty two skilled iron workers was sent by the Virginian Company to build a furnace and forge at Falling Creek. Some iron was produced but three years later the Indians attacked and destroyed the plant and massacred and scalped all the ironworkers" *(Source: Chronology of Iron and Steel, S.L.Goodale, Pittsburgh Iron and Steel Company 1920).*

Yours faithfully,
Tom Grey Davies. 20.2.74

Reply from Michael M Hallett

Sir,

It is always nice to find that someone actually reads what one writes and I am grateful for Tom Grey Davies's interest in the note on the Saugus Works. However, I am not very repentant as for all practical purposes Saugus was the first complete iron blast furnace in America.

There is no real evidence that Berkeley's Furnace at Falling Creek, Virginia, was ever completed or in operation, though it was unquestionably the first blast furnace, the construction of which was started in America. In late 1621 or early 1622 the Virginia company in London received from Berkeley a letter indicating that construction was under way and expressing optimism that the furnace would be in operation by Whitsun 1622. The massacre occurred on 22nd March 1622 and it is highly unlikely that on a new site the furnace would have gone into operation several months earlier than had been hoped for only a few months before hand. Invariably, pioneer workers are over-optimistic. A completed or nearly completed blast furnace structure is so massive that it would have been most difficult for the Red Indians to destroy effectively. If there had been a substantial part of the structure remaining, the known urge to recommence operations on the same site would have caused repair and starting up of the works, which did not happen. The inference is therefore that it was never close to completion.

It has to be admitted that, on the other hand, samples of slag were exhibited in Richmond, Virginia last century, as coming from Falling Creek, but the real provenance of this slag is most uncertain. It may even have come from much later operations on the same or a neighbouring site.

Yours faithfully,
M M Hallett 26.2.74

From Prof. Jerzy Piaskowski

Sir, In the last twenty years the metallographical examination of early iron implements has considerably developed.

A lot of papers have been published in different languages, not only in such well known languages as English, French, German, but also in Russian, Japanese, Czech, Polish, Hungarian, Bulgarian etc. In these works the range of analyses has been different, e.g. in some researches we lack the chemical analysis of the most important elements. There are also some differences in the analytical methods used, and the way of presenting the results *(in text, in tables, in diagrams)* are different too. This makes for great difficulty in comparative studies.

The study of the history of iron technology should not be limited to separate countries. It is necessary to track the directions of technological development through continents. So we must organise suitably all sources of information on the history of iron technology, specially the analytical data, taking into account the possibility of the use of computers, now and in future.

I think that it would be necessary to standardize the minimal range of examination and the analytical methods to make possible the comparison of data. It would also be possible to standardize the form of the reports, which would make possible the use of the analytical data and the technological results published in a language relatively unfamiliar to the reader.

Of course, my proposition is not against the freedom of investigators, but I think that such standardization is necessary in modern science and will enlarge considerably the field of studies.

This problem should interest the readers of the Journal of the Historical Metallurgy Society in particular, and all those investigating the history of technology of iron and steel. We ought to discuss this proposal for standardization.

Yours faithfully,
J.Piaskowski.

Zywiecka 40/12
30-427 Kraków, Poland.

Work in progress

FURNACES AT ECCLESHALL AND SHIFNAL, SHROPSHIRE

In the bulletin, 1973 Volume 7, Part 1 page 26-27, you published a report on blast furnaces in Shropshire. I can now report the analyses of slag and ore from the site of the blast furnace at Shifnal, and the slag from a neighbouring bloomery at Eccleshall.

A3, from Shifnal, would make a suitable ore from the blast furnace; the remainder of the composition would probably be water and carbon dioxide. The bloomery slag from this site, A4 and A6, could also form part of the charge. A5 is a very typical charcoal blast furnace slag which has been produced from coal-measure ironstone nodules with a limestone flux.

The analyses were made by the kindness of the British Steel Corporation, Special Steels Division, Swinden Laboratories.

Norman Mutton

CHEMICAL ANALYSIS OF SLAG AND ORE SAMPLES (%)
(Samples dried at 110°C prior to analysis)

			FeO	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	MnO	V_2O_5	TiO_2	Cr_2O_3	P_2O_5
A1	Eccleshall	Bloomery Slag	50.2	3.1	26.7	2.8	5.1	5.5	3.5	<0.2	<0.2	<0.2	1.0
A2	"	"	28.4	1.4	35.4	5.5	9.6	7.5	6.7	<0.2	0.2	<0.2	1.7
A3	Shifnal	Ore	0.8	66.4	14.8	3.2	0.3	<0.2	1.5	<0.2	0.2	<0.2	<0.2
A4	"	Bloomery Slag	51.5	15.5	27.6	2.1	0.3	<0.2	0.3	<0.2	<0.2	<0.2	0.4
A5	"	Blast Furnace Slag	5.0	0.4	51.8	18.2	13.5	5.0	2.3	<0.2	0.7	<0.2	<0.2
A6	"	Bloomery Slag	40.1	38.4	11.0	1.6	0.7	0.2	1.3	0.3	0.3	<0.2	3.8

Pippingford Blast Furnace, Sussex.

David Crossley has now completed his excavation on this 17th - 18th century blast furnace site *(TQ 450316)*. The base of the furnace, which was only about 1.5 to 2 m high, suggests a type not unlike that at Rockley in Yorkshire. Last year *(1973)* he had the good fortune to find a gun-casting complete with its head *(feeder)* still in place, which suggested that it had been scrapped as a faulty casting. X-radiography suggests that this may be a solid casting without a core. This year he has found the gun casting pit which is 4 m deep. This is stone lined at the top but lined with wooden staves lower down.

Early Iron Working Installation in Radovesice, North Bohemia, Czechoslovakia.

This was discovered during the excavation of a La Tène settlement in 1972 - 73. Presumably a reheating hearth is involved. Among the associated objects was an iron hammer.

J Waldhauser, Teplice, Czechoslovakia

The Medieval Bloomery at Olomoucany, Moravia.

Discovered in Ruzová street. This is the subject of the work by Mrs V. Souchopová. The excavation, having been a rescue action, did not allow uncovering of the whole area of the site. Nevertheless, two smelting furnaces and a huge amount of destroyed clay tuyeres were found. The furnaces are small *(dia. under 30 cm; preserved depth 35-40 cm)* but their refractory lining with layers and thickness of about 15-25 cms attest repeated renovations. In the vicinity various pits were found, some of them representing bunkers for building clays, fuel, or for throwing in refuse. Some iron nails were analyzed in the machinery works at Blansko, meanwhile pieces of blooms are being examined in the Archaeological Institute at Prague. According to pottery evidence the operations belong to the 10th cent. AD. Simultaneously, excavations are carried out on other similar localities in the neighbouring forests of the Drahanská plosina. This was a renowned iron-bearing region in the Middle Ages up to the 18th cent.

After V. Souchopová, Blansko, Czechoslovakia.

Blacksmith's Activities in the Medieval Castle of Saris, East Slovakia.

These were found during excavations necessitated by reconstruction operations on the castle. Finds included agglomerations of smithing slag and cinders *(13th cent.)* and fragments of clay crucibles.

After M. Slivka, Presov, Czechoslovakia.

Ninth Century AD Iron-Smelting Furnaces in Western Hungary.

During excavations in 1971-73, metallurgical sites with roughly 40 slag heaps were found at Nemeskér, Győr-Sopron province. The relevant area along the Siő brook was about 330 x 100 m wide. In the lower layer remains of 4 charcoal heaps were situated, whereas the upper level was occupied by the later walls of a workshop and by three shaft furnaces for smelting iron ore *(dia. 30-40 cms, height 70 cms).* Clay tuyeres 40 mm in diameter served in the blowing system. The bloomery used to be equipped also with hearths for reheating blooms and iron artifacts. Minor objects included blacksmith's tools *(tongs of differing size and a drift).* The pottery dates the site into the 9th cent. AD. The complex possibly represents a craft settlement, working in Avar territory and under Frankish supervision. All relevant material is kept in the Liszt-Ferec-Museum at Sopron.

J. Gömori, Budapest

Smithies dated from the 12th Century AD in Western Hungary.

A complex of pits being part of a smithy has been excavated in banks of the Válicska brook near Csatár, Zala province. One of the pits is believed to have been a smelting hearth *(115 x 180 cms, depth 60 cms);* another one could represent a refining installation *(250 x 270 cms).* Among bluish-green slags a denarius of Friesach was found *(1130 AD).* The pottery is in full agreement with this coin *(early 12th cent.).* J. Piaskowski *(Kraków)* carried out metallography on a set of iron objects *(buckles, nails, knives).* The techniques are said to be simple, the carburizing of metal being beyond the smith's close control. Nevertheless, one knife had a hardened blade. The ores were low in phosphorus *(P_2O_5 less than 0.5%).*

I. Valter (Budapest)

Excavations in the Burgenland, Austria were continued in 1973 in co-operation with the Austrian and Polish archaeologists.

These revealed further remains of late La Tène Smelting furnaces near the villages of Klostermarienburg and Raiding, Bez. Oberpullendorf *(on the latter site a large furnace ca. 100 cms in diameter came to light).* The sites, especially that at Klostermarienburg, were seriously damaged in earlier times.

A. Ohrenberger, Eisenstadt, and K. Bielenin, Kraków

New Field Work in the Holy Cross Mountains Area, Poland.

After a two year's intermission there were renewed excavations in the important late Roman period metallurgy centre. A bloomery, nicely arranged in two four-rowed groups of slag pit furnaces, was uncovered at Grzegorzewice, Opatów district. On the very end of the furnace-field a reheating or refining furnace was situated. It had been removed in situ and brought to the Archaeological Museum at Kraków, for further studies.

K. Bielenin, Kraków.

Research in Prehistoric Metallurgy in Turkey

In the summer of 1973 a project headed by ARIT Fellow, Prentiss S. de Jesus, and Ergun Kaptan of the Maden Tetkik ve Arama Enstitüsü (MTA) Natural History Museum was begun with the purpose of finding and recording ancient mining and smelting sites in Turkey.

Bibliographical and background work in libraries and in the MTA Archives during the year 1972 showed that the first summer's work would have to be limited to the Central Anatolian Plateau due to the great number of promising areas.

Following vague and confirmed reports of slag dumps and ancient mining activity, the survey investigated an area bounded by Bala, Beypazari, Eldivan, Yaprakli, Iskilip, Merzifon and Bogasköy. Close to 50 sites were visited and samples of the slags and ores were analysed in the MTA laboratory. There was a conspicuous lack of archaeological material on the sites, thereby making dating difficult. Some carbonized wood was found and sent to a C-14 laboratory for analysis. At least one of these analyses yielded an Early Bronze Age date.

As to be expected, most of the smelting sites were found in the mountains where water for ore preparation and wood for fuel are available. A great majority of the sites visited were seasonal. That is, the ancient smelter worked in that particular area for one season only, after which it was abandoned.

One may deduce from this that the ancient smelters worked during the fine weather only, this being long enough to smelt the metal requirements until the following season. None of the sites, save two or three, suggested intensive and long-lasting metallurgical activity. The exceptions are Karaali, south of the Ankara-Bala road; the Bakir Cay area north of Merzifon; and Karaca, a site in the Eldivan Mountains.

Ar Karaali a large slag mound represents copper mining and smelting activity from at least as early as Phrygian times to the Ottoman Period. The slag mound is estimated at 70,000 tons. A höyük in the same area is known to have yielded Phrygian and Hellenistic sherds. A large cultivated field (Tomo) near Karaali village contains many evidences of Byzantine habitation. Sherds, stone door sockets and architectural elements litter the ground. Coins have been found by the villagers in the fields.

Another instance of intense metallurgical activity can be seen in the Bakir Cay area. On the bank of the stream is a series of slag heaps. This area (Merzifon) is known to be in a rich copper-bearing zone. Malachite and chalcopyrite occur in abundance in the banks of the Bakir Cay. A few square foundations of stone were discovered near the slag heaps, these conceivably are former quarters of the ancient smelters. Soundings were not made in these foundations. No sherds could be seen on the surface of the ground. Dating of the slags will have to rely on the forthcoming C-14 results.

A third example of long-term smelting is reflected at Karaca Tas situated north of Yaprakli in the Eldivan Mountains. The slag dump lines the steep slope of a small river valley. Estimated slag can be put at 10,000 tons. Again, no archaeological material could be found to help in dating.

Native copper was found near the town of Eldivan and near Derekutugun (Bayat County). A source of chalcopyrite was located a few miles north of Sungurlu.

Tuyeres near the Bakir Cay were uncovered in a slag dump. These are the first reported tuyeres in Anatolia. A smelting furnace, the only one found in the survey, was uncovered at Hisarcikkaya near Eldivan, dating to the late Roman Period.

The material is now being studied in detail, and a full report will be published in the course of 1974 or early 1975.

In the summer of 1974 another survey is planned. Further investigation of selected sites on the Central Anatolian Plateau is envisaged in addition the Pontic coast, the Troad and the Manisa Plain.

Prentiss S. de Jesus
American Research Institute in Turkey.

ABSTRACTS

GENERAL

B.Ottaway. Early copper ornaments from Northern Europe. *Proc. Prehist. Soc. 1973,* **39** *(2), 294-331.*

The ornaments of the early cultures *(Neolithic-Chalcolithic-3400-2200 BC)* are composed of coppers made from native copper, oxide and fahlerz ores. There seems to be very little change in the type of ore used with date but the author suggests that the source of the native copper was probably the Romanian Siebenbürgen. The analyses considered are those determined by Junghans et al. and published in SAM I and II. The author uses a classification system based on the trace-minor element content. Briefly, the coppers with less than 0.001% of any element, apart from Ag and As, are classed as of native copper origin; those with many other elements *(e.g. Sn, Sb, Bi, Ni and Fe)* in the range 0.001-0.01% are said to be of pure oxide origin and the rest, often with 1.0 to 10% of Ag, As and Sb, are said to be of fahlerz origin. There were a number of specimens which remained ungrouped.

BRITISH ISLES

J.S.Forbes. Hallmarking gold and silver. *Chemistry in Britain, March 1971, 7 (3) 98-102.*

The history and present-day practice in marking articles, largely of gold and silver, is described briefly with illustrations of current and past marks and notes on the analytical methods used in testing articles. Cupellation is still the basic preliminary to analysis but spectrographic analysis is used in the examination of antique objects.

M.G.

T.R.Slater. The Old Blast Furnace at Maryport: Its Water Supply System. *Ind.Archaeology. Aug. 1973,* **10** *(3), 318-324.*

Further examination of documentary evidence and site investigations indicate that some corrections are needed to the account given by Tylecote, Banks, Wattleworth and Ashmore, JISI, 1965, 208, 867-874.

C.F.Tebbutt and H.Cleere. A Roman-British bloomery at Pippingford, Hartfield. *Sussex Arch. Coll. 1973,* **111,** *28-40.*

This site was found to contain a bloomery furnace and a smithing hearth. The smelting furnace is fairly typical with its back cut into the bank behind, with a slag-tapping pit in front. The back and front walls were made of stone set in clay and stood to a height of 40-50 cm; the internal diameter was about 50 cm. When excavated, the furnace was filled with slag which appeared to have been running into the tapping pit on a wide front. This "bear" weighed about 50 kg when removed piece-by-piece.

No signs of tuyeres were found; but it is clear that it would need more than one tuyere. In this respect and many others it is like the furnace found by James Money at Minepit Wood in the same county and reported in the last issue of the JHMS.

The smithing hearth was about 70 x 50 cm in plan and appeared to have a small adjunct at one end about 20 x 30 cm which could perhaps have been used for working up small objects. The slag heap was 65 m^2 and contained 11.5 m^3 of waste – mostly broken tap-slag, pieces of which weighed up to 15 kg. Other finds were ore, charcoal, pottery and a bronze brooch. The latter two items dated the site to the 1st cent. AD.

Maurice H.Ridgway. Chester Goldsmiths from early times to 1726. *Journal of the Chester and North Wales Architectural, Archaeological and Historic Society. 1966,* **53,** *198 pages.*

This is a well documented and illustrated book; it is a comprehensive and well researched piece of work. The Minutes Books of the Goldsmith's Company are extensively used, as are other primary and secondary sources.

Lists of Goldsmiths and their existing work appear in the book. Chester was an important assay centre, hence this book which contains adequate indexes.

Robert Sherlock. Chandeliers by Chester Brassfounders. *Journal of the Chester Archaeological Society, 1969,* **56,** *37-48.*

This paper starts by describing how chandeliers come to be designed and made. Then the author lists other areas producing brass chandeliers, with special reference to the north-west *(map),* and discusses patterns, and makes, and styles *(illustrated).* This well-documented paper concludes with a Schedule of Chandeliers manufactured by Chester Brassfounders.

Torsten Althin. Eric Geisler and his foreign tours, 1772-1773. *Med Hammare och Fackla, 1971,* **26,** *54-126. (In Swedish).*

This is an edition, in modern Swedish, of the technical notebook kept by Eric Geisler, an official of the Bergskollegiet, who toured Britain during 1772-3. The notebook proper, complete with all the drawings runs for some 46 pages. There is a comprehensive introduction of some 14 pages, in which the editor most ably and sympathetically shows Geisler to have been typical of his time; well versed and dedicated to his calling, yet curious and informed about all manner of other things, and particularly gifted in music. The article concludes with an extensive series of notes and a comprehensive biblography.

Material of metallurgical interest comprises notes on the Carron works, with some detail on the blowing engines and furnaces, anchor making at Swalwell, wire drawing at Barnsley, cutlery and cast steel manufacture at Sheffield, iron founding and lead rolling at Southwark, London. In addition to these, there are notes on coal and metal mining in the north country, and on lathes at London, as well as the non-technical information, such as the construction of pattens, and details of a magnificent bed which converted into a cupboard when not in use in day-time.

J.N.Rhodes. The Lead Mills at Mold. *Flintshire Historical Society Publications, 1971-2.* **25,** *21-30.*

These mills existed from 1597 to 1683; this study is based on documents belonging to the Duke of Westminster. Using an inventory taken at the time of sale the writer is able to describe contemporary smelting techniques and the organization of the enterprise. Seven men *(including apprentices)* worked two shifts, day and night.

Englishmen worked the mills and much of the lead went to London. Output was quite high except when the Royalists occupied the mills during the Civil Wars. After the Restoration prices of lead were high, output increased and much work was done in re-equipping the mill.

The second mill was built as a relief mill to maintain constant output when the other furnace was repaired or rebuilt. A further mill was built to step up production. Most of the ore came from the Halkyn Mines. The mills eventually closed because transport costs by packhorse were high to bring in the ore and send away the refined lead. New smelteries were built along the banks of the river Dee where the lead was easily sent away by water. The Mold Mills could not meet the growing needs, capital was short and the equipment became out of date. The site was used as a corn mill from 1700 to 1900 at least; maps and street names confirm the whereabouts of used mills. An interesting and well documented paper.

W.:..V.Gale. Conversion Rail. *Railway World. Oct. 197.,* **34** *(401), 438.*

An extensive system of 4 ft. 2 in. gauge plateways served the early transport needs of Dowlais Ironworks, but in 1838 or 1839 conversion rails were laid so that the tracks could be used either as plateways or 4 ft. 8½ in. *(standard)* gauge railways. Specimens of the 12 - 15 ft. long wrought iron rails rolled for this purpose were recently unearthed from a tip on the site of the old ironworks. A short piece of rail has been presented to the National Museum of Wales by the owners, G.K.N.Dowlais Ltd.

A.P.Lovat. Wealden Ironfounding – When Sussex was the Black County of England. *Foundry Trade Journal, Oct.11, 1973,* **135** *(2966), 480-482.*

An outline of the industry from the erection of the first furnace at Hartfield in about 1487 to the closing of the Ashburnham blast furnace in 1810 and forge soon after 1820. Prices fetched by the products at different times are quoted, including 6d. per lb. for the railings around St.Paul's cathedral, which were cast at Lamberhurst. The total bill for these railings was £11,202 plus £50 extra for pattern costs. A contemporary account of the working of a blast furnace at Cuckfield is quoted *(without date)* from an early volume of the Sussex Archaeological Collections.

Anon. Restoration Plan. *Foundry Trade Journal Oct. 18, 1973,* **135** *(2967), 516,*

The Yorkshire Dales National Park Committee has suggested to the North Riding County Council that the lead mine and smelting mill at Grinton, near Reeth, which were closed a century ago, should be preserved and used as a folk museum.

EUROPE

Josef Riederer. Metal analysis of bronze cannons. *Zeitschrift für Waffen– und Kostümkunde. (in German)*

From 59 bronze cannons from 1420-1860, the metal was analyzed by means of atomic absorption spectrometry. Besides the main compounds, copper *(86-94%)* and tin *(5-11%)*, lead *(0-1.6%, exceptionally 2-5%)*, zinc *(0-0.2%, exceptionally 0.2-2%)*, silver *(0.0.3%, exceptions 1%)*, antimony *(0-1.3%)*, and nickel *(0-0.5%)* were determined. The Pb/Ag, Pb/Sb, Ag/Sb, and Fe/Ni ratios were calculated in order to deduce from these the origin of the ores. The results were promising: 250 more cannons from the Heeresgeschichtliche Museum in Vienna were analyzed to enlarge the statistical basis.

J.R.

Olof Arrhenius. Corrosion on the warship Wasa. *Bulletin, No.48, pp.1-8 (1967). 7 photographs, 2 diagrams, 3 tables, 3 references.*

The extent of corrosion of metal objects on board the WASA *(which sank in Stockholm harbor in 1628)* is discussed. In particular, iron cannon-balls, lead bullets and copper coins were examined as the original weights and dimensions of these were known. The average extent of corrosion of the iron over 333 years was 40-50% *(average rust layer 14 mm)* although the calibre of the balls remained the same. The corrosion depth for the lead bullets was 0.85 mm and the corrosion loss of the copper coins was 880-3640 g/m^2 depending on the position of the coins in the ship. Experiments carried out over a period of five years under simulated conditions agree well with these figures. The cannon balls were treated in a hydrogen reduction furnace at 600°C and the lead bullets in a 10% ammonium acetate solution for half an hour followed by brushing and drying.

A.H.L.

Jan Szpak. The foundry of cannon balls in Ryjewo. *Kwartalnik Historii Kultury Materialnej, 1968,* **16** *(4) 691-705 (in Polish).*

The history of fire-arms production at the time of King Stefan Batory in Poland *(second half of 16th century)* is traced, including: an introduction, the equipment and location of the foundry, the process of production, the workers, the expenses and the amount of production.

H.J.

Alfred Mutz. A unique Roman bucket-handle. *Schweiss-Technik, Soudure, 1972 (62nd year), No.9, 263-266 (in French and German)*

A Roman bucket-handle found in Augst, near Basel, is described. Its uniqueness lies not in its nature, but in its structure; it is composed of two pieces of iron, an upper and a lower; in between which lies a sheet of bronze *(containing 5% tin)*. The possible reasons for this design and the techniques used are discussed. It seems likely that a forge-welding procedure was employed.

A.H.L.

Jean-René Maréchal. The spread of the direct process of the manufacture of iron by the Celtic and Germanic people. *(In French). OGAM - Tradition Celtique, December 1969,* **21** *(1-6), pp.275-291.*

The author summarizes studies on iron manufacturing methods from very ancient times. The Celts could conquer and occupy almost the whole of Europe thanks to their extraordinary production of armaments and iron tools. This was possible because of the wealth in iron of the European soil and by the use of relatively simple techniques very different from the ones used today.

J.B.

Leszek Kajzer. Some problems connected with the identification of "Roman" swords in Poland. *Prace i materialy Muzeum Archeologicznego i Etnograficznego w Lodzi, 1969 (16), 135-147. In Polish. French Summary.*

A.I.Bratus. A study of the metal of bridges with more than seventy years service. *Sbornik Trudov, Leningrad Inst. Inzh, Zhelez-dorog. Transp. 1971 (299) 115-25. (In Russian).*

Bridges of arch construction built before the end of the 19th century in Russia and other countries were studied. Chemical composition, mechanical properties and metallographic results are reported.

M.G.

E.Sangmeister. Spectrographic analyses of metal finds from the cemetery at Mokrin, Yugoslavia. In *Mokrin II, Beograd, 1972, 97-105. (in German).*

Analyses of 45 objects from Mokrin showed that the majority of those composed of copper belonged to the end of the Copper Age and not, as would be expected from the metal types represented, to the Early Bronze Age. Close scrutiny of the arsenical coppers revealed that the composition differed markedly from those of the Copper Age. It is suggested that arsenical copper was mixed with arsenically-free copper to give low As contents. Comparison with the Nitra group which has a similar As content as well as some Pb suggests that Mokrin could be as early as Nitra which is dated to phase I of the EBA. Many objects from Mokrin contain 0.013 to 2.5% Sn which is an unusual feature of the late Copper Age or EBA in South-east Europe. It is normally assumed that in South-east Europe tin-bronze was introduced in Phase II of the EBA.

P-L Pelet. Iron, charcoal and steel; an unappreciated industry in Vaud. *(in French). Bibliothéque historique vaudois, No.49, Lausanne, 1973.*

A book giving the results of important excavations of bloomery sites in the Jura of the 1st-5th cent. AD with full documentation.

A.K.Anteins. Damascene steel in the Eastern Baltic. *(in Russian). Riga, 1973; 137 pages and 146 figures.*

This book summarizes the author's intensive studies on pattern-welded weapons and knives. Deals with types of patterns and their technique for swords, lance-heads and knives. Gives details of composition, types of inscription and ornament on swords.

G.F.Carter and W.H.Carter. Chemical analysis of a plautia denarius. *Seaby's Coin and Medal Bulletin, No.560, 58-60 (February 1965). Photographs, table of analytical data, 4 references.*

The x-ray fluorescence analysis of a Roman Republican denarius of A.Plautius was carried out and the coin was found to be largely composed of tin and antimony (70.2 and 28 per cent respectively by weight). Another specimen, struck from different dies, was found to be primarily silver.

A.H.L.

E.Nosek. A fourteenth century forge at Siedlatków. *Prace I Materialy Muzeum Archeologicznego I Etnograficznego W Lodzi, Seria Archeologiczna, 1968,* **15**, *95-132. In Polish.*

Excavations at Siedlatkow in 1965/6 produced over 2000 metal objects which were divided into three groups: (a) tools (b) arms and armor (c) objects of everyday use. A selection of objects from each group was analyzed and subjected to metallographic examination. The region is one with a history of iron smelting, and analysis proved that local ones were used to make the artifacts. Technological observations are based on the analytical results.

The ample results are presented as a series of tables.

W.A.O.

Giles F.Carter. Compositions of some copper-based coins of Augustus and Tiberius. *Science and Archaeology, Cambridge Mass. 1971, 114-130.*

Seventy coins dated to last 1st cent. B.C. and early 1st cent. A.D. were analyzed by X-ray fluorescence. Weights and densities of the coins are given. The method is described and accuracy discussed, 6 coins minted in Antioch were essentially pure bronze *(Cu-Sn)* alloy.

E.W.F.

A.Chappus. Nickel silver and brass locksmithing. *Pro Metal, 25, 1972. (2), 7-9. (In French or German).*

Traditionally, locks and keys were made of iron; brass was used only for sea-chests, colonial-type furniture, pianos, etc. In the 1920's, safety locks were invented; for these nickel silver and brass were used. The development of safety locks since then is reviewed with examples.

L.S.Khomutova. Forging techniques in the medieval Russian town of Serensk *(12th-14th centuries). (In Russian). Sov.Arch.1973 (2), 216-225.*

Examined 106 specimens from both 12th-14th cent. and 7th cent. levels. They consisted of iron and steel with slag stringers. Blade construction of knives, axes, sickles and scythes was mainly by welding of iron and steel, but all-steel tools were relatively frequent.

V.D.Gopak and P.I.Khavlyuk. Iron working technology of the tribes of Zarubinskya culture in southern regions of the Buh river *(in Ukranian). Archeolohija. 1972(2), 90-96.*

Scythian techniques were observed in 8 iron, mild steel and iron to steel welded blades dating from the 1st cent. BC to 2nd cent. AD.

G.A.Voznesenskaya and B.V.Tekhov. Fabrication techniques used in smithed products found in the 10th-6th cent. BC necropolis of Tli. *Sov.Arch. 1973 (3), 153-162. (in Russian).*

A shortmetallographic survey of 28 iron tools and weapons found in the Caucasus. The structures showed steels made of unevenly carburized and piled iron, iron with externally carburized edges, iron-to-steel welding *(rare);* heat treatment had been used in one case, that of a battle axe, to give troostite.

ASIA

Kan'ya Tsujimoto. The casting techniques in the Nara period. *Ars Buddhica, October 1971, (82), 84-88. (In Japanese).*

The bronze casting techniques in the Nara period were discussed including the molds of sand and wax. 2 figs.

D.T.Bayard. Early Thai bronze: analysis and new dates. *Science June 30, 1972,* **176** *(4042) 1411-1412.*

Electron probe analysis of the earliest metal found at the northeastern Thailand site of Non Nok Tha indicates that it is a bronze containing 4 to 6% tin. Recent thermoluminescence dates substantiate the presence of a well-developed bronze technology prior to 2300 B.C. and suggest a date of about 2700 to 2500 BC for the first appearance of bronze at the site.

E.W.F.

Earle R.Caley. Analyses of some metal artifacts from ancient Afghanistan. *Science and Archaeology, Cambridge, Mass. 1971, pp.106-113.*

Thirty-one artifacts were analysed. 2 were unalloyed copper. 3 were low-tin bronze. 4 were high-tin bronze, with unusually high tin, ranging from 18-94 to 20.54%; comparison is made with high tin Chinese bronzes. 2 were leaded bronze (% lead > % tin). One was pewter *(tin-lead alloy).* 19 artifacts were iron or part of iron objects; 9 were completely rusted; of the remaining 10, one was steel and one cast iron.

E.W.F.

Ben. B. Johnson. Krishna Rajamannar Bronzes: an examination and treatment report. *Krishna: the Cowherd King by Pratapaditya Pal, Los Angeles County Museum of Art. Monograph Series, No 1, Calif. USA 62 pp.1972.*

A group of 4 Indian Chola bronzes were examined and cleaned prior to exhibition. A related South Indian study piece which had been discarded after casting provided much information about casting techniques. The bronzes were solid cast in a multipiece mold; the bases were cast separately. The surface was finished with various tools. The 4 pieces were analysed by mass spectrometry. Ultrasonic and mechanical cleaning were used. Resin on the surface was identified as crude dammar resin, probably from resin-burning in shrines. Acryloid B-72 *(3% in toluene)* was applied after cleaning.

E.W.F.

R.A.Key. The Cave's Treasure: Finds in the Cave at Sahal Mishmar, by P.Bar Adon. Trace elements composition of copper finds in Nahal Mishmar. *Book. Jerusalem, Israel, Mosbad Bialik, 1971, pp.242-247. Appendix (In Hebrew).*

The trace elements composition of 30 copper artifacts from the Cave at Nahal Mishmar are presented. The analyses were made by emission spectroscopy. The copper artifacts are the oldest decorative finds made by the "cire-perdue" method. The arsenical copper used suggests that the raw material was imported from Armenia or Azerbaijan, and not from Israel, Syria, Sinai or Cyprus.

Z.G.

R.Potashkin and K.Bar Avi. Metallurgical examination of two finds from the treasure in Nahal Mishmar. In the Cave's Treasure: finds in the cave at Nahal Mishmar, by P.Bar Adon. *Book, Jerusalem, Israel, Mosad Bialik, 1971, pp.239-241. Appendix. (In Hebrew).*

Two representative finds were analyzed. The chemical composition (%) has been determined by the usual methods.

Find	*Cu*	*As*	*Ni*	*Ag*	*Si*
A	95.1	4.1	0.3	0.20	0.20
B	99.5	0.27	nil		

Photomicrographs of the metals are given and conclusions are drawn as to the possible ways of manufacture of the tools.

Z.G.

Enver Behnan Sapolyo. Darphaneler. The royal mints. *Ön Asya. Dec.1969.* **5**, *(52) 12-13. (In Turkish).*

The author briefly summarizes the history of the Seljuk and Ottoman coins and describes the process of the making of coins in the Royal Mint :

1) "Dökümhane", where gold or silver is melted and is given the form of a "sikke" which is a metal bar 30 cm long 5 cm wide.

2) "Carkhane", where the 'sikke' is turned into sheets 1.5 m long and 5 cm wide and then coins are punched from it. Weighed coin 'pul' is milled.

3) "Sikkehane" where the faces of the coin are stamped.

4) "Kepce" where gold and silver, as well as the coins, are stored.

5) "Cesnihane" where the metals are tested.

A.T.

Cyril Stanley Smith. The techniques of the Luristan smith. *Science and Archaeology, Cambridge Mass. 1971, 32-52.*

Eight objects, dated 7th-9th Cent. BC were studied. They were analyzed chemically, and studied metallographically. The objects were daggers, short swords and mace heads. Aspects discussed are : the steel; general shaping techniques; mechanical joints *(in the short swords);* heat treatment; hardness.

E.W.F.

A.Gutkind Bulling and Isabella Drew. The dating of Chinese bronze mirrors. *Archives of Asian Art. 1971-2,* **23**, *36-57.*

An attempt is made to establish guide lines for distinguishing genuine ancient mirrors from later copies, either plain forgeries or made "in the style" of earlier mirrors. Use of x-radiographs, stereomicroscopic inspection and chemical analysis are described. The most important criterion developed here is the establishment of a table relating the diameter and weight of a given mirror to its age. In general, earlier mirrors of a given diameter are lighter than later mirrors of the same diameter. 12 mirrors from the Arthur Sackler collection, are illustrated, in two cases with radiographs, and are treated individually, with stylistic description and technical comments for each.

E.W.F.

Anon. Genius of the Chinese Founder. *Foundry Trade Journal. Nov.15, 1973,* **135** *(2971), 641-644.*

A review of the Chinese Exhibition staged in 1973-74 at the Royal Academy, London which emphasises the new light thrown on the earliest development of foundry practices in Eastern Asia. Excavation of a complete bronze foundry at Houma, Shansi, brought to light a number of pottery moulds dating back to the late 5th or 4th century BC including a three piece mould for the production of ornamental tigers (illustrated), and a number of patterns, also in pottery. Inspection of castings from the earliest times (1600 BC) indicates that the commonest method for casting was to carve and engrave clay moulds freehand without recourse to a pattern, though models were occasionally used. The joints in the clay moulds did not always fit perfectly with the result that lines of flash appeared on the final casting. As time went by, these became incorporated in the design, so that heavy vertical flanges are a common feature at the corners of bronze holloware. Chaplets were also employed to locate cores within the mould. Only in the Period of the Warring States (475 – 221 BC) did the lost-wax technique become the predominant production method, enhancing still further the decorative styles.

During this period the use of cast iron moulds for the repetitive production of hoes, spade tips and axes became common. A twin cavity die for the multiple production of sickle blades and cast die components for making socketed axes are illustrated. It is not certain whether these moulds were used for casting in bronze or iron. Melting and casting techniques found illustrated on the wall of a tomb in Eastern Han were portrayed in the exhibition, though this article questions the metal temperature of 1500°C stated to have been attained for casting iron.

The centre piece of the exhibition was the jade funeral suit of Princess Tou Wan (Western Han Dynasty, 206 BC – 8 AD). The tunnel leading to the tomb was found to have been blocked by a great iron door cast in situ. Apparently a cavity wall was constructed across the tunnel and molten iron run into the space between.

N.N.Terekhova. The metallography of metal artifacts from the Eneolithic village of Geoksur *(in Russian). Sov. Arch. 1974 (2), 167-179.*

The site lies in one of the largest centres of early agriculture in Central Asia. The village dates from the 4th-3rd millennium BC. The paper gives a detailed description of the fabrication techniques and the various categories of objects and tools produced. Most of the objects examined were bars and rods; there seems to have been some unfinished hilted daggers and knives. The metal was copper with various amounts of cuprous oxide; it was hot or cold worked and annealed with some final cold working giving a hardness up to 137 kg/mm². It is concluded that the village functioned as a workshop which specialised in finishing imported semi-finished material.

O.Werner. The spectrochemical and metallurgical analysis of Indian bronzes. *Brill, Leiden, 1972, 268 pages. (In German with an English summary).*

A reference book for metallurgists and museum staffs. Covers the region from India to China and contains 400 new analyses. Contains a valuable bibliography. This book is fully reviewed by E. van Someren on page 430 of Metals and Materials for October 1973, Vol.7.

A.Ts.Guevorkian. The earliest sources of copper-bearing minerals in Armenia. *Sov. Arch. 1973 (4), 32-39.*

Describes the archaeological investigation of the mining areas and gives a spectrographic analysis of specimens of oxide minerals from which preliminary conclusions are developed regarding the role of certain mines in the early metallurgy of Armenia. It appears that the capacity of these mineral sources has been severely overestimated. Only a half of those inspected are of a type satisfactory to the miners of antiquity. Some of the others were practically inaccessible in high antiquity. A table of analyses is given which shows that the copper content was in the range 1-10%; As and Sb were absent but traces of tin in the range 0-0.01% were present in two cases.

AFRICA

Peter A.Clayton. Royal bronze Shawabti figures. *Journal of Egyptian Archaeology, August, 1972, 58, 167-175.*

Royal bronze shawabtis are rare and hitherto the authenticity of some has been doubted. Four were subjected to scientific examination at the Research Laboratory, British Museum; the earlier two were virtually pure copper, whereas the later ones were bronzes, which is in accordance with the composition of other metal objects of the same period. Examination of the corrosion products on the objects confirmed the authenticity of the shawabtis.

M.R.C.

T.G.H.James. Gold technology in ancient Egypt. *Gold Bulletin. April 1972, 5, (2) 38-42.*

An illustrated discussion of the use of gold sheet and foil by Egyptian craftsmen in the period around 1400 BC. Most of the metal came from the mountainous region between the Nile and the Red Sea. Gold wire and granules were used for jewellery, and small pieces were made by casting.

M.G.

AMERICA

Warwick Bray. Ancient American metal-smiths. *Proceedings of the Royal Anthropological Institute of Great Britain and Ireland. 1971, pp.25-43, 16 drawings, 21 plates, 1 map, 145 references.*

In this paper, the mining, production and working of metals in early America are discussed. Descriptions of materials, implements and techniques are given.

A.H.L.

TECHNIQUES

H.Cleere. Notes on the study of early iron industries. *Science and Archaeology. Oct./Dec. 1970 (4), pp.4-7.*

Scientific examination

The paper attempts a methodological analysis of the study of early technology, taking the iron industry as an example. The first section deals with preparatory research; fieldwork, study of maps and air photographs, record searching, etc. Excavation is dealt with in the second section; the author emphasizes how excavation of an industrial site requires modification of the standard techniques. The third section is concerned with the examination of finds, and touches on scientific examination of artifacts and structures and their classification. In the final section, attention is given to the compilation and analysis of technological data resulting from fieldwork and excavation, and its publication.

A.A.

Joachim Emmerling. Technological examination of iron artifacts. *Alt-Thüringen, 1972. 12, 267-320 (In German).*

Formerly, technological examinations of iron objects were done only sporadically. Today, a close cooperation between the historian and the scholar of the natural sciences is required, which ought to lead to comparable examination results. Analyses of ores and drossy material give only limited results. Differences in technologies, hints about distribution of work, differences of material and of the execution of the work are given. There are extensive explanations with very detailed illustrations of welding iron, its structure, hardening and damascening.

R.-D.B.
(trans. W.A.)

Robyna Ketchum. Bells ..... and how they are made. *National Antiques Review. May 1972, 3, (11), 16-17.*

The article deals briefly with the various techniques for making and casting bells. Information on how to date bells by style and metallic content is also given.

Four black and white illustrations show various steps in the processes of making bells.

A.Z.L.

Bernhard Osann. The direct process and the origins of pig-iron production *(on the metallurgy and heat technology of early iron production). Fachausschussbericht, September 1971 (9.001) 2-170. In German.*

The metallurgy of iron and steel production from Iron Age to recent times is discussed, on the basis of archaeological material and modern experiments. Particular reference is made to the reduction processes and the formation of slag.

(8 tables of data, many photographs, diagrams, maps, and plans. 74 refs.)

A.H.L.

Heather N.Lechtman. Ancient methods of gilding silver. Examples from the old and new worlds. *Sci.Archaeol., Symp. Archaeol. Chem. 4th. pp.2-30 (1968 pub.1971). Edited by Robert H.Brill, MIT; Cambridge Mass.*

Material from Turkey and Iran (3rd-6th centuries AD) and the northern coastal region of Peru *(400 BC – 100 AD and 1000-1470 AD).* are compared. True gilding is the external application of gold whereas depletion gilding is the enrichment of an alloy surface containing gold by dissolving or otherwise removing the other metals in the alloy. Various ancient and modern gilding methods are discussed along with some laboratory experiments on gilding. Various analytical techniques, especially the electron microprobe, were used. One of the objects from the Near East was gilded with gold leaf, and the other four were gilded by mercury amalgam techniques. The Peruvian objects showed no residual mercury, but the parent alloys contained 7-10% gold, suggesting that a cementation of depletion gilding process *(a process known in the area)* was used. An application of gold leaf to the surface is still a possibility.

SCIENTIFIC EXAMINATION

David L.Shirey. Metropolitan bronze horse proves to be ancient. *The New York Times. Sunday Dec.24, 1972. p.37B.*

The Metropolitan Museum's famous bronze horse which was declared to be a fraud in 1967, has been declared an "irrefutably genuine work of antiquity" after a thorough technical examination, which included thermoluminescence, radiography, testing with solvents, and examination of the core material. The misleading "sandcasting seams" were removed by solvents; they were apparently caused by reproduction casts made of the horse. The metal was analyzed and found to be a copper-tin alloy with low concentrations of lead, zinc, and other metallic trace impurities. Thermoluminescent dating of the core material was said to provide "definitive evidence that the horse was made in ancient times." Thermoluminescence is explained in some detail. The reasoning behind the decisions and stylistic features are also discussed. A radiograph of the horse in question and three other black and white photographs are reproduced.

J.E.H.S.

C.C.Patterson, T.J.Chow and M.Murozumi. The possibility of measuring variations in the intensity of worldwide lead smelting during medieval and ancient times using lead aerosol deposits in polar snow strata. *Scientific Methods in Medieval Archaeology, Univ. of Calif. Press. 339-350 (1970). Illus.*

Lead concentrations in the upper two centuries of snow layers near the north and south poles have been measured. The reconstruction of world silver production, and as a corollary, world lead production, in ancient times would be of considerable interest *(Silver was obtained by smelting it out of lead)*, as part of a study concerned with recent air pollution.

E.W.F.

Adon A. Gordus. Neutron activation analysis of streaks from coins and metallic works of art. *Report. COO-912-24, 28 pp. (1970). Available Dep. NTIS.*

From Nucl. Sci. Abstr. 1972, 26(7), 14659. Two nondestructive methods of activation analysis of coins and art objects are described. The first method consists of irradiating a coin for one minute in a low-intensity neutron source followed by a one minute analysis of the induced Ag radioactivity. Using this method, the silver fineness of a coin can be determined to 1-1.5%. The 2nd method consists of removing the corrosion layer on a tiny area of the coin or art object by stroking the edge with a fine-grained emery paper. A small, clean piece of roughened quartz tubing is then rubbed on the brightened area of the coin edge producing a streak on the tubing.

A. Van Dalen, H.A. Das and J. Zonderhuis. Non-destructive examination of Roman silver coins by neutron activation analysis in 2nd international conference on forensic activation analysis *(texts of papers)*, **paper 14, Glasgow, September 1972.** *Book. Glasgow, Western Regional Hospital Board, 11 West Graham Street, Glasgow, G 4, 9Lf, 1972, 13 p. £5.*

2000 silver coins from the 1st century BC were subjected to neutron activation analysis with a view to detecting "plated specimens."

The Au/Cu ratios of the coins were measured, these ratios having been shown to be proportional to the Ag/Cu ratios. For a plated coin, the Au/Cu ratio is of the order of 10^{-4} and for a non-plated coin it varies between 10^{-1} and 10.

(3 tables, table 2 giving the percentage composition of twenty selected coins (Ag, Cu, Au and Pb) and table 3 giving the silver content of 1776 coins broken down into groups. 5 references, 1 graph).

A.H.L.

Anon. Renovation of a 16th cent. gun – by treatment in a hydrogen oven. *Hoyt Notched Ingot, November, 1973 (111), p.25.*

The gun was salvaged from the **Mary Rose**, sunk off Portsmouth on 11 July 1545. The treatment and preservation of such an object after prolonged submersion in sea-water is usually both difficult and unsatisfactory. Mr. C. O'Shea of the Portsmouth Museum, having heard of similar treatment in Sweden, made arrangements with EMI-Varian of Hayes, Middlesex to use a hydrogen oven which is normally used in the production of advanced electron tubes. This oven had to be big enough to take the gun-barrel which measures 1200 mm x 305 mm dia.

The barrel was gradually heated in a continuously flowing mixture of 10% hydrogen and 90% nitrogen. At 300°C large quantities of water were evolved, increasing as temperature rose. At c.750°C the ferric chloride was reduced to HCl gas, which, with the water, was tapped off by specially inserted pipes. A final temperature of 1050°C was held for several hours after which the quantity of reduction products fell. After cooling, the barrel was inspected and it was found that the rust had been almost wholly converted to iron. After sealing to exclude the possibility of water absorption, the gun-barrel was removed to Portsmouth and impregnated with a low melting point polyvinyl chloride. The result of this treatment has led Mr. O'Shea to plan the installation of a hydrogen oven at the Museum for future renovation attempts for objects recovered after prolonged immersion.

The Editor would like to acknowledge the help he is receiving with the abstracts. He is very grateful to the following who are actively participating:- D.R.Howard, J.W.Butler, W.Haldane, P.S.Richards, T.Daff, H.F.Cleere, H.W.Paar, N.Mutton, E.Raub, A.P.Greenough, J.K.Harrison, W.A.Oddy, M.M.Hallett, J.Piaskowski, K. Poplawska and A.P.Woolrich. Some of the abstracts are taken from the periodical "Art and Archaeology Technical Abstracts" and we are grateful to the International Institute for the Conservation of Historic and Artistic Works, London and New York, for allowing us to reproduce them. We are also grateful to Dr.R.Pleiner, honorary secretary of the Iron Committee of the International Union of Prehistoric and Protohistoric Sciences for allowing us to reproduce items from the Bulletin of that committee.

HISTORICAL METALLURGY SOCIETY 1973 1974
officers and accounts

President	Professor H.O'Neill
Chairman	Dr R.F. Tylecote
Honorary Secretary	Mr K.C. Barraclough
Honorary Editor	Dr R.F. Tylecote

Committee:

Mr D.W.Crossley	Mr W.K.V.Gale	Prof. D.G.Tucker
Mr R. Day	Mr M.M.Hallett	Mr B.M.Hardman
Dr N. Swindells	Mr W.A.Oddy	

Representatives:

The Metals Society	Prof. H.O'Neill
Royal Anthropological Society	Mr B.E.B. Fagg
Council for British Archaeology	Mr K.C.Barraclough

RECEIPTS

Balance brought forward from 1972 Account			831-65
Subscriptions:	1972	5-45	
	1973	432-21	
	1974	23-25 *	
	1975	3-76 *	
	1976	0-50 *	465-17
Donation			5-00
Sale of £500 7% Brit. Sav. Bonds			500-93
Dividends from 7% Brit. Sav. Bonds			24-88
Contribution by J.H. Money towards cost of publication of paper			125-44
Sales of back numbers of Bulletins and offprints			81-98
A.G.M. Bristol 1973 Receipts			40-00
Annual Conference – Keele – 1973 Receipts			662-90
			£2 737-95

* These amounts will not be taken into 1974 account.

PAYMENTS

Subscription to C.B.A.			13-00
Subscription to Ironbridge Gorge Museum			3-00
Editor's Expenses			12-87
Hon. Secretary's Expenses			9-58
Hon. Treasurer's Expenses			5-00
Postage Account			80-80
Purchase of £500 7% Brit. Sav. Bonds			500-00
Purchase of £500 8½% Brit. Sav. Bonds			500-00
Books bought for stock and library			27-50
Cost of English translation of Swedish B.F. Report			39-60
Cost of reprinting back numbers of Bulletin			39-36
Grants:	Mr Davies Shiel	25-00	
	Thaxted Guild Hall	5-00	
	Mr D.W.Crossley	15-00	
	Mr Torsten Berg	10-00	
	Mr N.Mutton	15-00	70-00
A.G.M. Bristol 1973 Cost			54-00
Annual Conference – Keele – 1973			
	Accommodation	570-55	
	Coaches	50-00	
	Gratuities	2-00	
	Printing	14-08	
	Projector	3-00	
	Postage	9-70	
	Refunds	6-00	655-33
Transfer to Research and Publication Account			232-82
Balance at Bank – 31st December 1973			495-09
			£2 737-95

(Signed) N.Swindells, Chairman

Charles Blick, Hon.Treasurer
24.4.74

J.B.Widdop, Hon.Auditor