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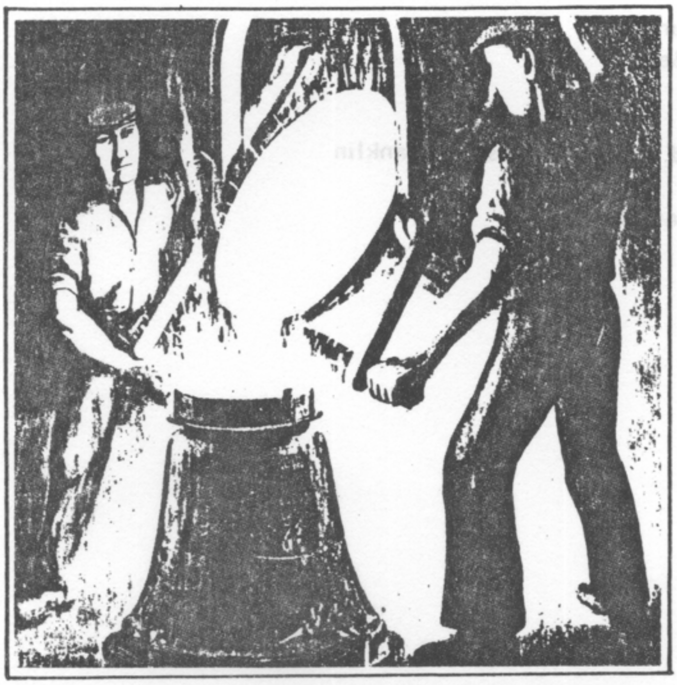

Sign of the Bell Inn, Bristol, painted by David Fisher

Contents

The evolution of the Cowper Stove

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Summary

Cowper Stoves are used in conjunction with the blast furnace to burn the hot waste gases coming from the top of the furnace and to use the heat to preheat the blast. The Cowper Stove operates on a regenerative principle, which means that first the hot waste gases are passed through channels in the Cowper Stove and then the cold air blast is passed through the same channels, and so on alternately.

This paper sets out to indicate the developments, beginning at the turn of the Nineteenth Century, which eventually led to the patenting of the Cowper Stove in 1857. It shows how the pioneers slowly overcame both the limitations of the technology of their day and the conservatism and ignorance of their fellow-workers. An evaluation of the contributions of the early workers perhaps gives some credence to the words of David Mushet:
"Whilst the exploits of the conqueror and the intrigues of the demagogue are faithfully preserved through a succession of ages, the persevering and unobtrusive efforts of genius, developing the best blessings of the Deity to man, are often consigned to oblivion."

A. SUPPLY OF AIR CURRENT

From ancient times man employed a blast of cold air to enhance the reactions within the iron-smelting furnace, developing bellows for the purpose. These wooden or leather bellows were originally manpowered, but with the advent of the blast furnace proper it became necessary to use some form of mechanical power. Water power, the only suitable form available at first, was widely used.

Gale[1], in his excellent book, reports that it was only with the introduction of Watt's steam engine[2] that the supply of blast was appreciably improved. He says that although Newcomen's engine[3] was the forerunner of Watt's it had little connection with iron-making although one instance of its use to furnace blowing was known to Gale.

Further to this, Swank[4] records that "The manufacture of pig iron with mineral fuel was greatly facilitated by the invention of a cylindrical cast-iron bellows by John Smeaton[5] in 1760, to take the place of wooden or leather bellows ..... being used for the first time .... at the Carron iron works in Scotland", and in his earlier and very famous book Scrivenor[6] reports similarly. In accepting Swank's information Fisher[7] adds that the apparatus, initially water-driven, was subsequently powered by Newcomen's engine and only later by Watt's engine. However, Schubert[8] tells us that only with Watt's invention "did the best results come".
Certainly during the period 1750–1800 much effort was directed toward increasing the force of the blast, which was to prove so important to the 19th century iron industry.

B. BLAST FURNACE WASTE GAS

A by-product of the furnace reactions is the hot waste gas. Although of low calorific value (most authorities until recently gave a figure of 2700-3000 joules/m^3 for modern plants but subsequent advances have reduced the figure even lower) it is inevitably produced in large quantities, continuously, and at a high temperature.

Dearden's figures[9] give a guide to its constituency, agreeing fairly well with figures given by Petit[10]:—

Constituent Gas	Percentage by volume
Nitrogen	58 - 60
Carbon monoxide	27 – 30
Carbon dioxide	8 – 11
Hydrogen	1 – 3

Its leanness is made apparent when its calorific value (now down to about 2400 joules/m^3) is compared with those of coal gas (~15,000) and natural gas (~30,000).

Formerly the waste gas was allowed to burn freely at the throat of the furnace, which proved to be rather an embarrassment as the heat generated interfered with charging.

C. USE OF WASTE GAS

In the early years of the 19th century attention was turned to the utilisation of waste gas. Rhead[11] surmises that "waste gas was beginning to be used by 1809". The reliable Percy[12] says that "In June 1814, Berthier published an interesting and important paper on the successful application in France of the waste gas to various purposes .... M Aubertot .... obtained a patent for it in France in 1811[13] ... The calorific effect of the waste gases was rightly attributed by Berthier partly to the sensible heat and partly to the heat developed by combustion in contact with atmospheric air."

This passage is most illuminating for it has been commonly held that not until some twenty years later was the actual heat of combustion of waste gas used.

Although little precise information is available it is clear that much experimental work was being carried out in the period 1810–28. For example, in 1827 John Urpeth Rastrick introduced his "waste-heat boiler" for raising steam by extracting heat from puddling furnace waste gas[14]. Then soon after 1828 events took a new turn. Some ironmasters became interested in preheating the blast, and one way of accomplishing this would be by extracting heat from the furnace waste gas.

D. HEATING THE BLAST

Ironmasters in the 18th century and early 19th century were aware of a phenomenon which misled them badly. Furnaces operated more efficiently in winter than in summer. It was concluded, not unnaturally, that the colder the blast the better would the furnace function. Some operators[15] even went so far as to pass the blast air over cold water on its way to the furnace "in order to cool it further and thereby increase efficiency". In fact, the air temperature variation was unimportant and what really mattered was the humidity of the air. The lower humidity of air in winter implied a higher oxygen content, and it was oxygen that was required to promote the reactions in the furnace. It is not surprising, then, that when the Scot, James Beaumont Neilson (1792–1865), claimed that the blast should be heated this suggestion was met with derision.

His argument that by using some fuel to preheat the blast a greater saving of fuel would be made within the furnace was quite sound, but as Gale[1] remarks: "Set against the knowledge and practice of Neilson's time the idea was revolutionary and, to many people quite absurd". Clements[16] and Fairbairn[17] state that Neilson had made his discovery by 1824, but virtually all other writers give 1828 as the year. Actually his investigations began in 1824, culminating in the patent four years later and practical success in 1829.

E. NEILSON'S INVENTION

In his elegant patent Neilson[18] stated that the blast was to be "passed continuously through one or more externally heated chambers". He suggested that these chambers be made of iron and the external heat supplied by an enclosed (coal) fire. He envisaged his device being used for "fires, forges, and furnaces" but probably had little idea of its immense importance for the iron industry.

His device was basically a RECUPERATOR in which two fluids flow through contiguous channels and heat passes through the dividing wall from the hotter fluid to the colder. The 'hotter fluid' was the burning gas from a fire, passing round the walls of the heating chamber. An essential feature of the recuperator is the thinness and strength of the dividing wall. This proved to be a real difficulty for Neilson, as he realised that a very hot fire was required for the best results.

Major trials of the invention went on in 1830 at the Clyde Iron Works, under Neilson's own supervision. His earliest apparatus was crude: attached to each blast furnace tuyere was a wrought-iron heating chamber which was externally heated by a coal fire, the blast being heated to about 95°C during its passage through the chamber. Unfortunately the intense heat rapidly destroyed the chambers, which had to be replaced with ones of the more durable cast-iron, a blast temperature of 140°C then being obtainable. This was quickly raised to 315°C as further adaptations were made, the incorporation of the water-cooled tuyere being particularly important.[19]

That increased production resulted from hot-blast was clearly demonstrated by Neilson. Thomas Clark set out details to show this, in a paper read to the Royal Society of Edinburgh in 1835[20], by which time hot-blast had become well established in Scotland. Figures taken from Clark's paper, together with further information supplied by Scrivenor[21] show the remarkable saving made at Glasgow, for comparable weeks of different years, using the same apparatus:

First six months of	Tonnes coal per tonne cast iron	Blast	Coal for blast heating	Overall ratio
1829	8.06*	cold	–	8.06:1
1830	5.15*	heated 150°C	0.4	5.45:1
1833	2.25	heated 315°C	0.4	2.65:1

*coal first converted into coke, not necessary with the higher temperatures obtained in 1833.

According to Smiles[22], Neilson was approached by an ironmaster who was seeking guidance as to how to improve summer working of the furnace and was of the opinion that excessive sulphur in the summer air was the cause of the poorer working. However, "Mr Neilson was rather disposed to think it attributable to the want of a due proportion of oxygen in summer, when the air was more rarified as well as containing more aqueous vapour than in winter", which was quite correct. Neilson's confidence and enthusiasm were well-placed, but he could hardly have perceived that his discovery was "one of the most important improvements ever made in Metallurgy" as Percy so appositely described it. By his persistence and enterprise, Neilson rendered a tremendous service not just to the iron trade but to the whole world, and his work was indeed recognised outside the industry itself, and in 1846 Neilson was elected a Fellow of the Royal Society.

The Scottish ironmasters were at first unreceptive of Neilson's idea, but the results which he obtained at Glasgow were so remarkable and their desire to economise so keen that the iron masters soon began experimenting with hot-blast themselves. Indeed, their diffidence rapidly gave way to such contagious enthusiasm that Scotland's very last cold-blast furnace was in the process of conversion to hot-blast in just 1835[20]. The saving to Scotland for the year 1845 was estimated to be about 2 million tonnes of coal!

There was rather less advantage in England in the use of coal as the direct blast furnace fuel, since good coking coal was plentiful, and although Gale[14] reports that "by the middle of the 19th centure . . . hot-blast . . in the Black Country had become more or less standardized", this was not true for all parts of the country until much later.

Ironmasters were all too willing to use hot-blast, but without paying for the privilege[22,23]. Neilson therefore instigated a number of lawsuits, the most renowned of which he brought successfully against William Baird & Company in May 1843. The firm had failed to honour their agreement to pay him one shilling per ton of iron produced using hot-blast. Their case was that his 1828 patent was far from original and cited "a patent of Robert Stirling dated 1816" in an attempt to prove this. It is useful, then, to examine Stirling's specification. A temporary setback in this is that the patent (No. 4081) was "never enrolled" and no official trace of it exists. Fortunately the Iron & Steel Institute published the specification in 1886[24].

The following extract from his specification, to be read with reference to Figure 1, is well worth recording:—

two currents of liquid . . . which are made to run in opposite directions."

This remarkable extract shows the main idea conceived of by Stirling to be that of the REGENERATOR. His outline of the principle of the RECUPERATOR is almost an aside. In view of this it may appear surprising that Neilson won his case against William Baird's. It is not clear on what grounds the case was fought. A transcript of the trial was published in Edinburgh in 1843 and both Percy and Smiles were familiar with it but the only known copy was destroyed during the last war.

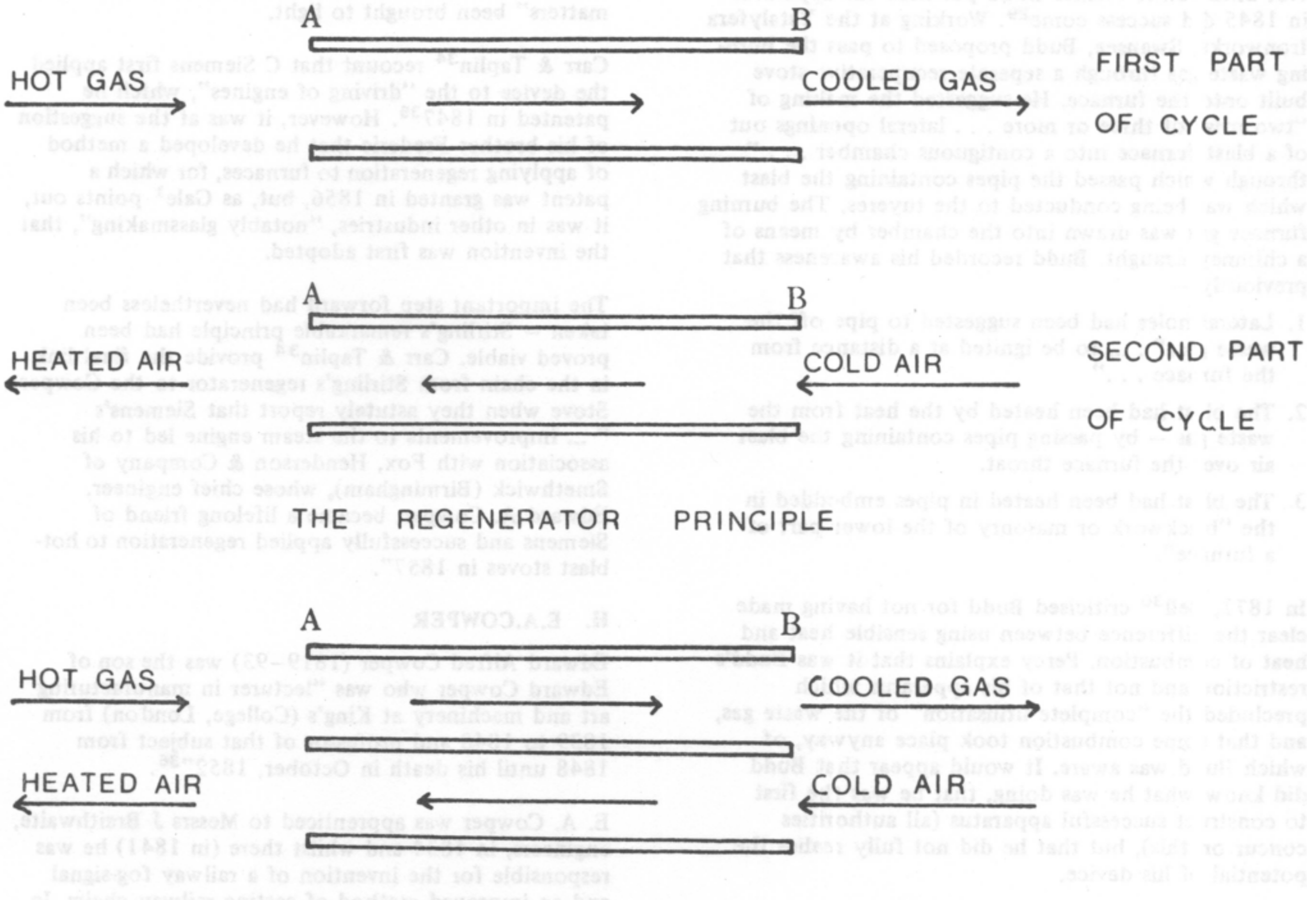


fig 1

"The hot . . . fluid . . . to be cooled is made to enter the passage at A and to pass along to its other extremity B. In its progress, it gives out its heat to the sides of the passage and issues at B, at nearly the original temperature of the passage. In this manner, the extremity at A and a considerable portion of the passage is heated to nearly the temperature of the hot fluid, while the extremity B still retains its original temperature nearly. When the temperature of the passage at B has been raised a few degrees, the motion of the fluid from A to B is stopped, and a portion of fluid which is required to be heated . . . is made to traverse the same passage in a contrary direction, ie. from B to A, by which means it receives heat from the sides of the passage . . . and so on alternately. . . . The second modification . . . consists in interposing a thin plate of metal or other material . . . between

This, then, was the era in which recuperation held sway and Stirling's brilliant regenerative principle was not to be applied successfully in the iron industry until the late 1850's.

F. BLAST HEATING BY MEANS OF WASTE GAS RECUPERATION

The twin notions of waste gas utilisation and blast heating were gradually brought together after 1828, and for some thirty years many attempts were made to realise the merger practically. In 1832 Moses Teague took out a patent[25] which came very close to the idea, making practical a suggestion put forward by Aubertot[12,17,26]. Teague states in his noteworthy patent that:

"This improvement consists in making use of or employing the flame and heat (heretofore discharged into the open air) from the tops or tunnel heads of blast furnaces by means whereof the said flame and heat is made to act upon the ores, mines, and minerals about to be smelted previous to the same being deposited into the interior of the furnace."

According to Turner[27], Faber du Faur invented a "hot blast stove heated by the combustion of the furnace waste gas" but no trace of this can be found[28]. This evidence somewhat discredits the widely held belief that it was from Wednesbury that the idea originated, where trials commenced in 1834.

Not until James Plamer Budd patented his apparatus in 1845 did success come[29]. Working at the Ystalyfera Ironworks, Swansea, Budd proposed to pass the burning waste gas through a separate recuperative stove built onto the furnace. He suggested the making of "two rows of three or more . . . lateral openings out of a blast furnace into a contiguous chamber . . . " through which passed the pipes containing the blast which was being conducted to the tuyeres. The burning furnace gas was drawn into the chamber by means of a chimney draught. Budd recorded his awareness that previously:–

1. Lateral holes had been suggested to pipe off the waste gass" ... to be ignited at a distance from the furnace . . ."
2. The blast had been heated by the heat from the waste gas – by passing pipes containing the blast air over the furnace throat.
3. The blast had been heated in pipes embedded in the "brickwork or masonry of the lower part of a furnace".

In 1872, Bell[30] criticised Budd for not having made clear the difference between using sensible heat and heat of combustion. Percy explains that it was Budd's restriction and not that of his apparatus which precluded the "complete utilisation" of the waste gas, and that some combustion took place anyway, of which Budd was aware. It would appear that Budd did know what he was doing, that he was the first to construct successful apparatus (all authorities concur on this), but that he did not fully realise the potential of his device.

As Gale[1] comments, "after 1845 future efforts were directed at taking off the gas, unburnt, at the furnace top, conveying it in pipes to ground level, and there burning it under a boiler or in a . . . stove". Lloyd[31] outlined in 1860 the various early attempts to take off the gas, and thereby produced a long list of failures. No satisfactory method of taking off the uncombusted waste gas was found until the furnace top was fully closed in a way which yet permitted periodic charging, which was successfully done by G Parry in 1850 when he introduced the "cup and cone" at Ebbw Vale[12], and even then difficulties kept cropping up[14].

G. SIEMENS'S DEVELOPMENT OF THE REGENERATIVE PRINCIPLE

From 1846 onwards Carl Wilhelm Siemens (1823–83), the eminent inventor, set about finding the most efficient mode of producing available heat by combustion[32]. His research led him to Stirling's regenerative principle, and he proceeded to develop the idea practically for various industrial purposes.

Commentators on Siemens's work hitherto have apparently overlooked a paper by Head & Pouff[33] presented to the Iron & Steel Institute in 1889, in which it is recorded that Robert Stirling "with his brother James" developed at Dundee a "regenerative air engine" which worked as well as any steam engine of that day. The Stirling borthers are also recorded as having foreseen the possibility of using the regenerative principle in metallurgical furnaces, but nothing came of this. Head & Pouff also mention two abortive attempts to use regeneration for furnaces: by Slater (in 1837) and Laming (in 1847). It is probable that Siemens was unaware of these efforts – for the 1889 paper includes the remark that "only very recently" had "these matters" been brought to light.

Carr & Taplin[34] recount that C Siemens first applied the device to the "driving of engines", which he patented in 1847[35]. However, it was at the suggestion of his brother Frederic that he developed a method of applying regeneration to furnaces, for which a patent was granted in 1856, but, as Gale[1] points out, it was in other industries, "notably glassmaking", that the invention was first adopted.

The important step forward had nevertheless been taken – Stirling's remarkable principle had been proved viable. Carr & Taplin[34] provide the final link in the chain from Stirling's regenerator to the Cowper Stove when they astutely report that Siemens's "... improvements to the steam engine led to his association with Fox, Henderson & Company of Smethwick (Birmingham), whose chief engineer, Edward A. Cowper, became a lifelong friend of Siemens and successfully applied regeneration to hot-blast stoves in 1857".

H. E.A.COWPER

Edward Alfred Cowper (1819–93) was the son of Edward Cowper who was "lecturer in manufacturing art and machinery at King's (College, London) from 1839 to 1848 and professor of that subject from 1848 until his death in October, 1852"[36].

E. A. Cowper was apprenticed to Messrs J Braithwaite, engineers, in 1834 and whilst there (in 1841) he was responsible for the invention of a railway fog-signal and an improved method of casting railway chairs. In 1846[37] he joined Fox, Henderson & Company, with whom he remained until 1851 when he set himself up as a consulting engineer in London. There is no reference to Cowper's being concerned specifically with blast furnace practice early on, but after associating with Siemens he designed and patented his stove[38].

I. BLAST HEATING BY MEANS OF WASTE GAS REGENERATION

It is clear that in order to have a continuous supply of blast more than one regenerator must be employed. Cowper proposed using two, one imparting heat to the blast whilst the other absorbed heat from the gases of the fire employed, the roles of the two regenerators being interchanged periodically (about every two hours at first). His patent[39] of 1857 contained many interesting features:–

1. Changeovers to be effected by operating water-cooled valves.
2. Refractory material either "thrown at random" or built up in various ways to form channels for the passage of the gases.

3. Different refractory material according to the position in the regenerator: "plates or pieces of iron" for the cooler region and "firebrick" for the hotter region.
4. Crooked flues to promote heat exchange between gas and solid.
5. Perforated and studded firebricks to improve heat exchange.
6. "A fan or blowing machine" to increase the draught, where necessary.
7. "In some cases, in lieu of employing a separate fire or fires for heating the regenerators, I heat them by the waste heat or gases from a blast or other furnace."

The patent contained details of seven designs of heating apparatus, six of these involving a pair of regenerators, the other being a recuperator. Cowper did not, "claim generally the application of 'regenerators' to furnaces", but what he did claim can be seen by reading reading his 'Provisional Specification', which is reproduced in Figure 2.

Furnaces at this time were usually about 12m to 15m high. (Cowper proposed that the stoves would be about the same height as the furnace as can be seen by looking at a drawing taken from his patent, reproduced in Appendix B). By 1870 furnaces up to 30m were tried, but, working at a blast pressure of about $30kN/m^2$ a maximum height of 25m was found to be best. Blast temperatures commonly attained in the late 1850s were $400^{\circ}C$ to $430^{\circ}C$ and by the mid 1860s temperatures of about $540^{\circ}C$ were not unknown[34]. Cowper had attained a blast temperature of $700^{\circ}C$ in 1860[40].

J. THE IMPORTANCE OF COWPER

In 1957, to mark the centenary of Cowper's patent, Daniel Petit[41] wrote an article[42] in which he briefly reviewed Cowper's work, including the patent itself, of which he gave prominence to the following points:—

1. Principles of gas reversals.
2. The use of crooked flues.
3. Use of perforated refractory plate.
4. Advantages of high blast temperature.

[Second Edition.]

fig 2

A.D. 1857 . . . . N° 1404.

Furnaces.

LETTERS PATENT to Edward Alfred Cowper, of Great George Street, Westminster, in the County of Middlesex, for the Invention of "IMPROVEMENTS IN FURNACES FOR HEATING AIR AND OTHER ELASTIC FLUIDS."

Sealed the 7th August 1857, and dated the 19th May 1857.

PROVISIONAL SPECIFICATION left by the said Edward Alfred Cowper at the Office of the Commissioners of Patents, with his Petition, on the 19th May 1857.

I, EDWARD ALFRED COWPER, of Great George Street, Westminster, in the County of Middlesex, do hereby declare the nature of the said Invention for "IMPROVEMENTS IN FURNACES FOR HEATING AIR AND OTHER ELASTIC FLUIDS," to be as follows:—

The mode at present employed for heating the blast for iron furnaces consists in driving the air through iron pipes inclosed in and heated by a furnace. The temperature thus obtainable is restricted on account of the injury which iron pipes sustain when exposed to a fierce fire, and also to pressure. Pipes of fire clay cannot be employed in the ordinary furnaces, as they would leak or crack, and the air would escape. By the present Invention I am enabled advantageously to employ fire clay or fire stone, or similar refractory materials, and I can thus heat the air to a very high temperature. For this purpose the air is heated by means of "regenerators," in which the same passages are employed alternately for the products of combustion and the air; or alternate and separate passages or chambers are used, in which case the

2 A.D. 1857.—N° 1404. Provisional Specification.

Cowper's Improvements in Furnaces for Heating Air and other Elastic Fluids.

air is raised to and maintained at the same or nearly the same pressure in the furnace, and the chambers or passages communicating with it, as the pressure of the blast itself. The regenerator consists of a chamber filled with fire bricks, or other refractory substances, having interstices between them for the passage of the air or products of combustion. The regenerator is enclosed in an air-tight case of iron, or other suitable material, lined with fire bricks, or other refractory and bad conducting materials. The flame and products of combustion of a fire are conducted through this regenerator, and the bricks or other materials within it become highly heated at the end at which the flame enters, while the other end remains comparatively cool. When the regenerator has thus absorbed a certain quantity of heat, the entrance of the products of combustion is stopped, and the blast of air is passed through in the contrary direction. The air is thus heated by the bricks to a very high temperature, and is conducted from the regenerator to the smelting or blast furnace. While the blast is thus being heated by one regenerator, another regenerator is being heated by the same or a different fire to that which heated the first regenerator.

When the heat of the first generator is exhausted or partially exhausted, the second regenerator is brought into action, and the first is again heated by the fire. The reversing of the currents is effected by valves or cocks, which are protected from the heat or made of materials capable of withstanding the heat, or so constructed as to be capable of resisting the heat, either by introducing water within or around the valves or their seats, or by employing valves which drop into water or other liquid, or melted or fusible metals or alloys, or otherwise. Or the apparatus is so arranged that the valves or guides for the passage of the air and products of combustion may be exposed to the same or nearly the same pressure on each side. In this case the furnace may consist of a series of parallel or crooked flues or passages. The products of combustion of the fire are passed through the alternate flues, and the air is passed through the other alternate flues in the opposite direction. The whole is enclosed in an air-tight case. In some cases, in lieu of employing a separate fire or fires for heating the regenerators, I heat them by the waste heat or gases from a blast or other furnace.

The Invention is applicable for heating air, or steam, or gases, or vapours under pressure for blast furnaces, or for any purpose for which the same may be required. By this Invention I am enabled to obtain a much hotter blast than can be obtained by the ordinary furnaces, and with great economy of fuel.

5. Use of fan to accelerate combustion.
6. Use of metal checkers.

Petit went on to claim that "Cowper showed himself to be unquestionably an inventor of genious" – but what evidence is there to support this assertion? The points mentioned by Petit will be examined individually.

1. In his patent Cowper gave clear and precise details about how to operate his various devices, including the hot-blast stove. This was undoubtedly valuable to operators and future designers alike.
2. Cowper laid little emphasis on crooked flues, and the idea was certainly not novel, being mentioned in F. Siemens's patent of 1856, for example[43].
3. His refractory brick designs and arrangements for the regenerator were both original and important. In discussing arrangement of brickwork Luhrmann[44] wrote in 1890:

   "In the Cowper stove the bricks were at first arranged loosely, without any binding material, exactly as in the older forms of Siemens's regenerator chamber." Luhrmann went on to describe the more sophisticated patterns which were later adopted and said that the formations producing vertical flues only came into use in 1875. It would appear, then, that perhaps Cowper did not use or develop the idea himself, and was presumably unsure of its value.
4. Cowper's design made an important contribution to the industry in that it made possible much higher blast temperatures and he made every effort to improve his stove to this end. However, he was not "the voice of one crying in the wilderness" for Cochrane, Samuelson, Forbes, Whitwell and C. Siemens were all supporters of this contention[34] which Bell[31] and Gruner[45] mistakenly found so unacceptable.
5. In proposing the use of a fan Cowper was merely repeating the suggestions of others: de Meckenheim (1842), Bovill (1846), Cuvier (1854) and F. Siemens (1856) for example[43,46–48].
6. The great Stirling himself had foreseen the possibility of using metal refractory in the cooler part of the regenerator, and in Siemens's 1856 patent is to be found: "The partitions may be advantageously made of metal plate so arranged as to form zig-zag or tortuous channels."

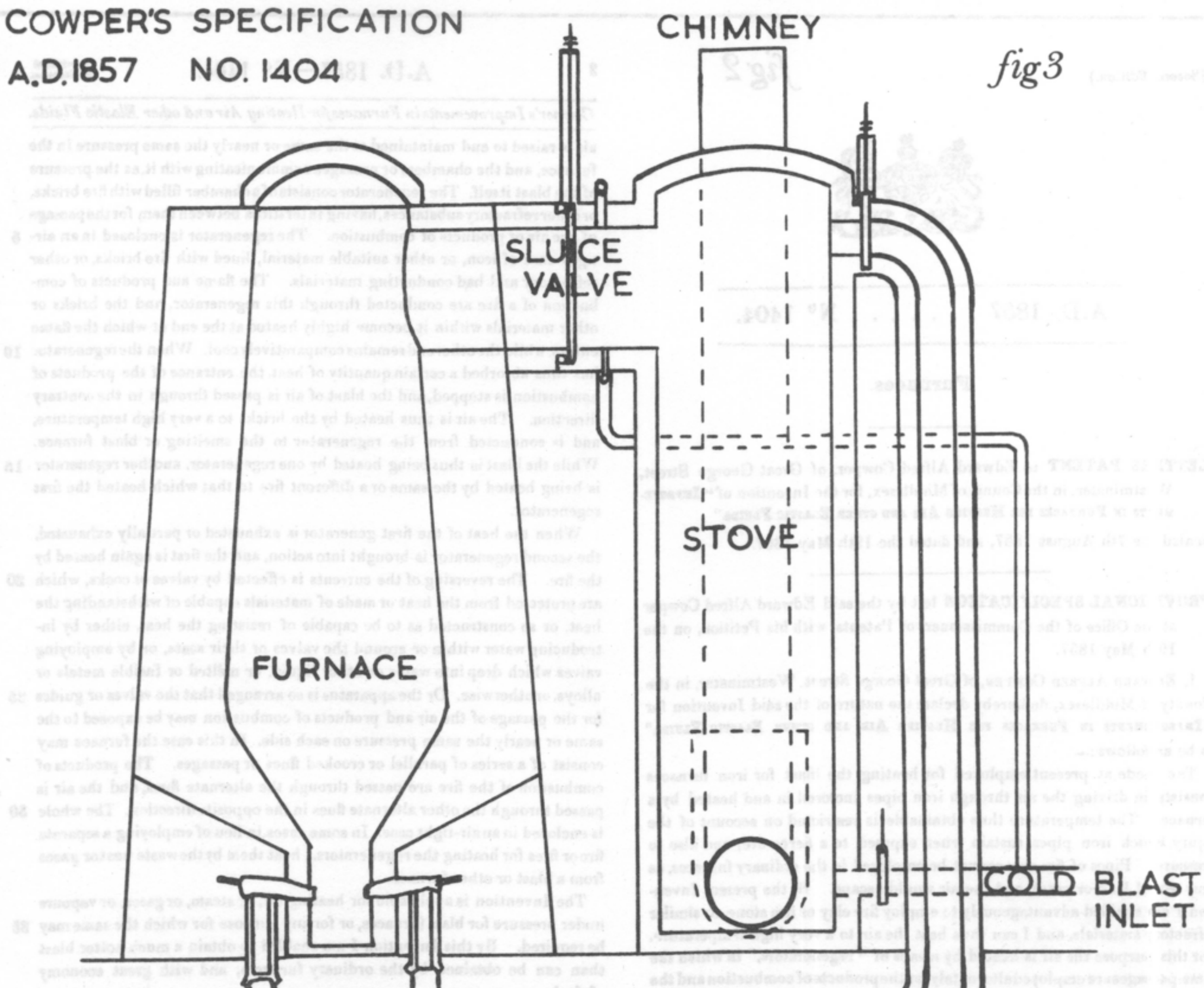


fig3

In trying to estimate the contribution of Cowper the following passage from Percy[12] probably written in 1862, is helpful:—

"Mr Siemens, the inventor of the so-called regenerative furnaces, than which, in my judgement nothing can be more philosophical in principle, proposed to employ blast at a much higher temperature than hitherto, considerably exceeding even a red heat; and the proposal has been carried into practice by my friend, Mr I. Lowthian Bell, at the Clarence Iron Works, near Middlesboro'-on-Tees. No advantage, however, was derived from thus heating the blast. Great inconvenience is reported to have been experienced from the accumulation of dust in the regenerative chambers, and the Siemens's hot-blast stoves have been abandoned at these works".

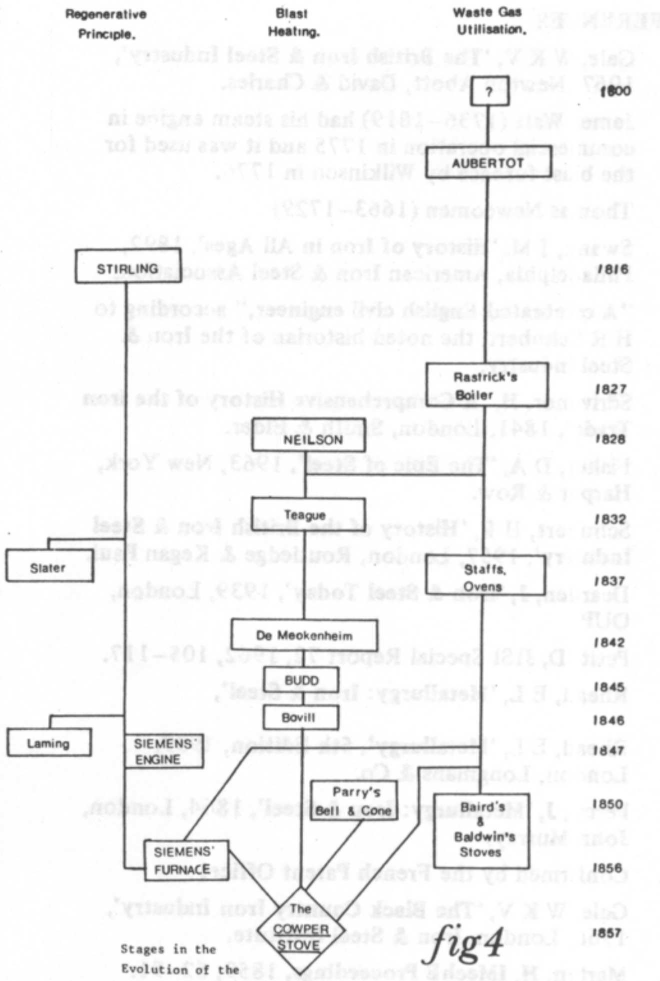
However, in a footnote Percy adds:—

"Since the above was in type, I have been informed by Mr Cowper that hot-blast stoves on his method of construction have been in successful operation for upwards of two years at the works of Messrs. Cochrane & Co., at Ormesby, near Middlesboro'-on-Tees; and that the result has been a saving of 5 cwts. of coke per ton of iron made, and an increased make from the same furnace of more than one-third. The blast is heated considerably above redness."

We see that Cowper was able to improve Siemens's design and reduce the trouble from dust blockage, which was no mean achievement. Whitwell's stove, patented in 1868[49] was to be a further improvement in this direction[50].

There was, then, little in the patent to indicate any remarkable powers on Cowper's part, and it was more in the practical running of his stoves that he excelled. Cowper was a very good practical engineer but evidence of brilliance is lacking. Bell[30], who had definitely put Cowper's invention into effect at his Clarence Works by 1861, succinctly remarked "Mr Cowper patented Mr. Siemens' ideas of what he calls his regenerative system" — and that was that! Petit perhaps hoped that overstatement would bring Cowper further recognition, but Cowper stoves themselves are a fitting memorial — *"Si monumentum requiris, circumspice"*.

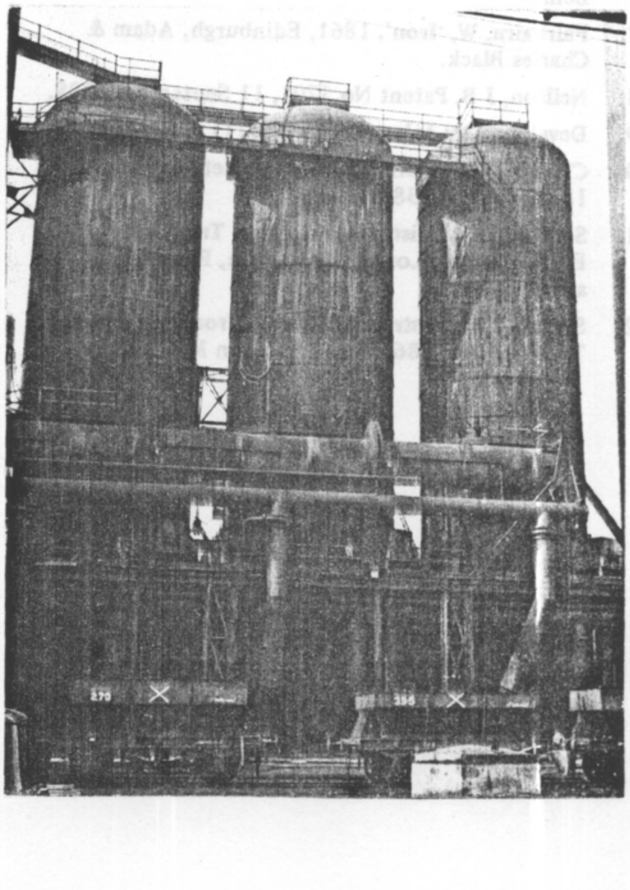
Cowper was undoubtedly an excellent engineer, but not a genius. It is then, appropriate to salute all those men of the 19th century who contributed in theory or practice to the development of hot-blast implementation, especially Stirling, Neilson and the Siemens brothers. The Cowper stove, to which they, as did so many others, contributed so much, is a constant reminder of their tremendous efforts. They would no doubt be intrigued to see the complete picture of the story of hot-blast (Figure 4) and the blast furnace stoves as they are today Figure 5



Stages in the Evolution of the Cowper stove.

fig 4

fig 5 →



ACKNOWLEDGEMENTS

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REFERENCES

1. Gale, W K V, **'The British Iron & Steel Industry'**, 1967, Newton Abott, David & Charles.
2. James Watt (1736–1819) had his steam engine in commercial operation in 1775 and it was used for the blast furnace by Wilkinson in 1776.
3. Thomas Newcomen (1663–1729)
4. Swank, J M, **'History of Iron in All Ages'**, 1892, Philadelphia, American Iron & Steel Association.
5. **"A celebrated English civil engineer,"** according to H R Schubert, the noted historian of the Iron & Steel industry.
6. Scrivenor, H, **'A Comprehensive History of the Iron Trade'**, 1841, London, Smith & Elder.
7. Fisher, D A, **'The Epic of Steel'**, 1963, New York, Harper & Row.
8. Schubert, H R, **'History of the British Iron & Steel Industry'**, 1957, London, Routledge & Kegan Paul.
9. Dearden, J, **'Iron & Steel Today'**, 1939, London, OUP.
10. Petit, D, JISI Special Report 72, 1962, 105–117.
11. Rhead, E L, **'Metallurgy: Iron & Steel'**,
11. Rhead, E L, **'Metallurgy'**, 5th Edition, 1939, London, Longmans & Co.
12. Percy, J, **'Metallurgy: Iron & Steel'**, 1864, London, John Murray.
13. Confirmed by the French Patent Office.
14. Gale, W K V, **'The Black Country Iron Industry'**, 1966, London, Iron & Steel Institute.
15. Marten, H, IMechE Proceedings, 1859, 62–91.
16. Clements, F, **'Blast Furnace Practice'**, 1929, London, Benn.
17. Fairbairn, W, **'Iron'**, 1861, Edinburgh, Adam & Charles Black.
18. Neilson, J B, Patent No 5701, 11 September 1828.
19. Developed by John Condie. See (1) and (16).
20. Clark, T, Transactions, Royal Society of Edinburgh, 1835, 23, 373–382.
21. Scrivenor, H, **'History of the Iron Trade'**, 2nd Edition, 1854, London, Longman, Brown, Green and Longmans.
22. Smiles, S, **'Industrial Biography: Iron Workers & Tool Makers'**, 1863, London, John Murray.
23. Muir, A, **'The Story of Shotts'** undated ca. 1954, Edinburgh, The Shotts Iron Co. Ltd.
24. **'Specification of Rev Dr Stirling's Invention'**, JISI, 1886, 29, 831–838.
25. Teague, M, Patent No 6211, 17 January 1832.
26. Bauerman, H, **'Metallurgy of Iron'**, 1868, London, Virtue.
27. Turner, T, **'The Metallurgy of Iron'**, 5th Edition, 1918, London, Griffin.
28. British and French Patent Offices have no record of it.
29. Budd, J P, Patent No 10475, 16 January 1845.
30. Bell, I L, **'Chemical Phenomena of Iron Smelting'** 1872, London, Routledge.
31. Lloyd, S, IMechE Proceedings, 1860, 251–276.
32. Jeans, J S, **'Steel'**, 1880, London, Spon.
33. Head, J and Pouff, P, JISI, 1889, 256–264.
34. Carr, J C and Taplin, W, **'A History of the British Steel Industry'** 1962, Oxford, Blackwell.
35. Siemens, C W, Patent No 12006, 22 December 1847.
36. Private communication from the Librarian, King's College, London.
37. Petit (42) gives 1848 as the year.
38. Obituary Notice of E A Cowper, JISI, 1893, 172–173.
39. Cowper, E A, Patent No 1404, 19 May 1857.
40. Cowper, E A, **'On Some Regenerative Hot Blast Stoves..'** IMechE Proceedings, 1860, 54–73.
41. President of the Sociéte de Technique Industrielle, Paris, at that time.
42. Petit, D, 1957, JISI, 185, 501–509.
43. Siemens, F, Patent No 2861, 2 December 1856.
44. Luhrman, F W, JISI, 1890, 754.
45. Gruner, L E, Studies of Blast Furnace Phenomena', 1873, London, King.
46. De Meckenheim, L N, Patent No 9373, 31 May 1842.
47. Bovill, G H, Patent No 11067, 31 January 1846.
48. Cuvier, V G A, Patent No 1519, 11 July 1854.
49. Whitwell, T, Patent No 112, 11 January 1868.
50. Hogan, W T, **'Economic History of the Iron and Steel Industry in the United States'** Vol I Parts I and II, 1971, Lexington (Mass), D C Heath & Co.

Iron smelting at Taruga, Nigeria

by R F Tylecote

The site of Taruga lies on a fairly flat terrace of about a hectare raised a few metres above two small streams which flow northwards to form the Takushara river about 13m below the site. This river gives its name to the nearest village which is in the Emirate of Abuja in the northern province. It is about 55 km south-east of Abuja.

The settlement of Taruga belongs to the Nok culture, an Iron Age culture that is clearly responsible for the famous terracotta figurines which have been found both at Taruga and many unstratified deposits in the tin-bearing gravels south and west of the Jos plateaux of Central Nigeria. A number of C–14 dates have been obtained from isolated finds of this culture which have given dates round about the last few centures BC. Three dates have been obtained from Taruga itself. Two of these are from occupation levels, 280 ± 120 and 440 ± 140 BC; and one from below a continuous slag layer in furnace No 2 gave a date of 300 ± 100 BC. There is no doubt that the iron smelting furnaces discussed below belong to the settlement itself and not to a later date[1,2].

The thirteen furnaces excavated are all basically the same type of low shaft furnace and consist of pits dug into the ground or decomposed bedrock to a depth of about 30 cms, with walls standing from a few cms to as much as 20 cms high (Figure 1–3). In all but two of the furnaces the pits were lined with clay. An important feature of these pits was the way in which their diameter increased with depth resembling furnaces found in Jutland dated to the 4th century AD[3,4].

The furnaces varied in diameter from 36 to 105 cms at the top of the pit. Wall thickness varied from 3 cms to 18 cms, and the walls appeared to have been made from the same lateritic earth as the local round huts. The lining of the pits was fired black, as would be expected from the reducing conditions maintained within them. The walls were mostly red burnt. Not all the furnaces were circular; three were slightly oval, one of these varying from 41 cms on one axis to 58 cms on the other.

Some of the furnaces were filled with little more than collapsed furnace wall and seemed to have been cleared of slag ready for re-use. Others – particularly the smaller ones – were full of slag which appeared to be in some cases the product of a single smelt. Several of the pits had slag sticking to the lining in some places, as though no slag had formed in the centre or else had been cleared out. Others contained a complex fill of isolated pieces of slag, furnace wall, and bits of fallen-in tuyere.

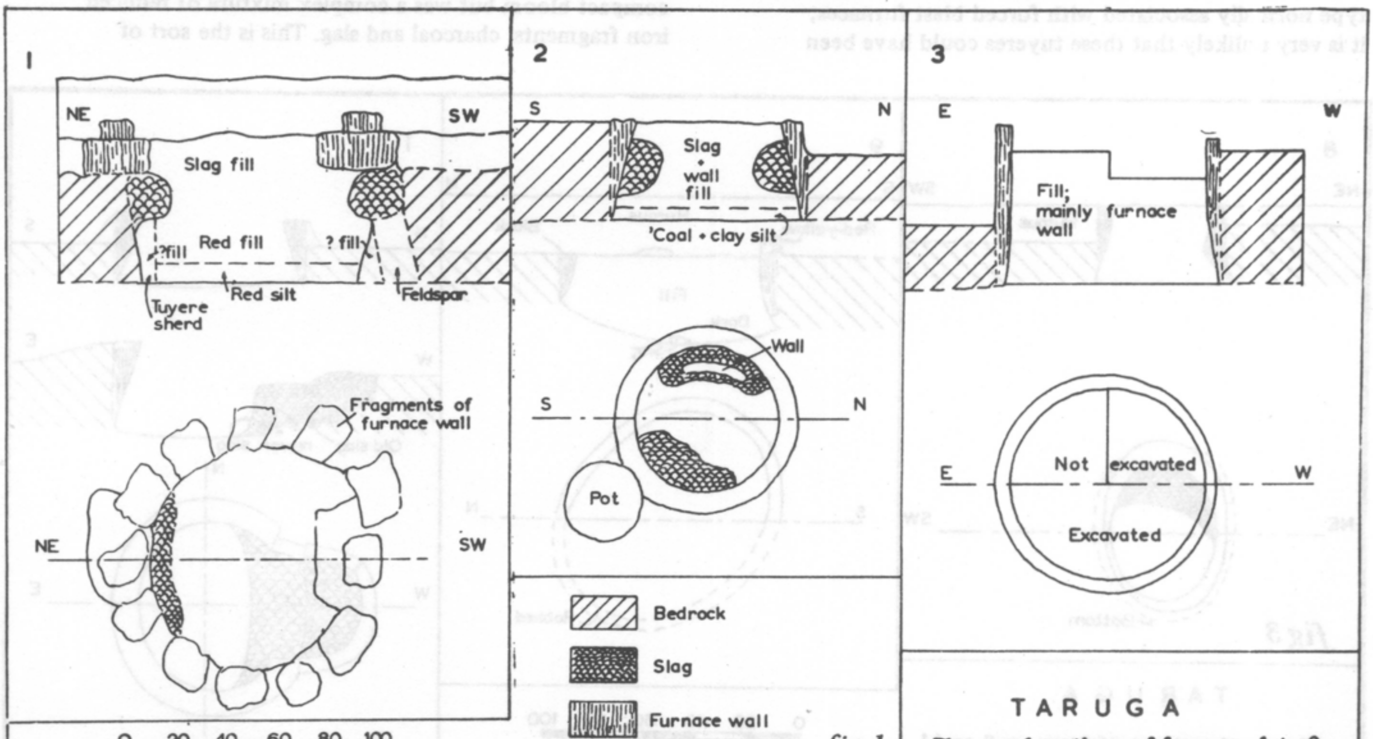


fig 1

TARUGA
Plans and sections of furnaces 1 to 3

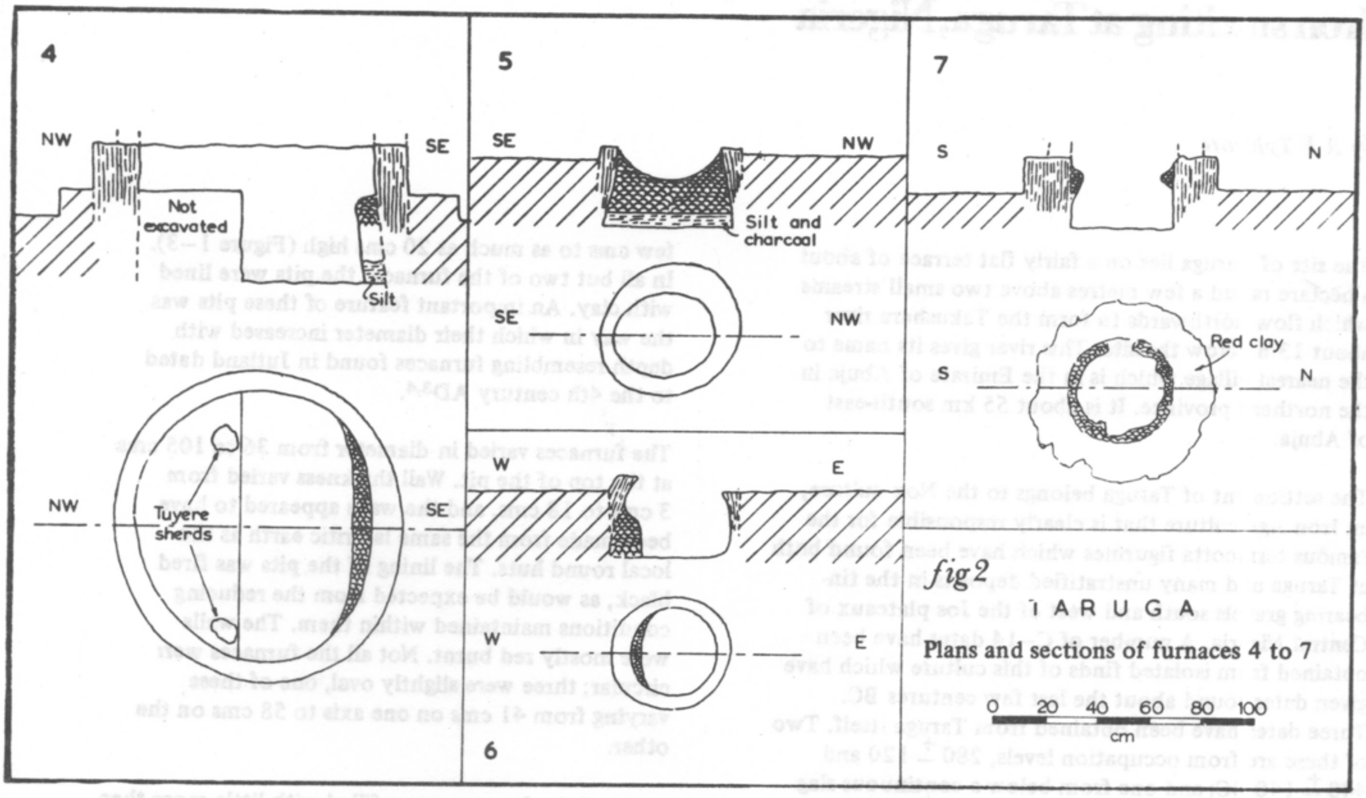


fig 2

TARUGA

Plans and sections of furnaces 4 to 7

In no case were tuyeres found *in situ*, and it appears that in all cases they had been fixed in the part of the furnace wall that had collapsed.

The tuyeres were all of the same pattern with walls about 3 cms thick and an internal diameter varying from about 3 to 5 cms; their length was about 12 cms, except for one which was 25 cms long (Figure 4). No complete tuyere has been found but they seemed to have been a type normally associated with forced blast furnaces; it is very unlikely that these tuyeres could have been used for induced blast as the latter all seem to be more than 60 cms long with very thin walls.

The slag was of the fayalite type always found associated with the bloomery or direct process, but most of it was in small pieces (Table 1). No unworked blooms were found although a considerable number of small artifacts turned up. It therefore seems very likely that the product of smelting was not in the form of a single compact bloom but was a complex mixture of reduced iron fragments, charcoal and slag. This is the sort of

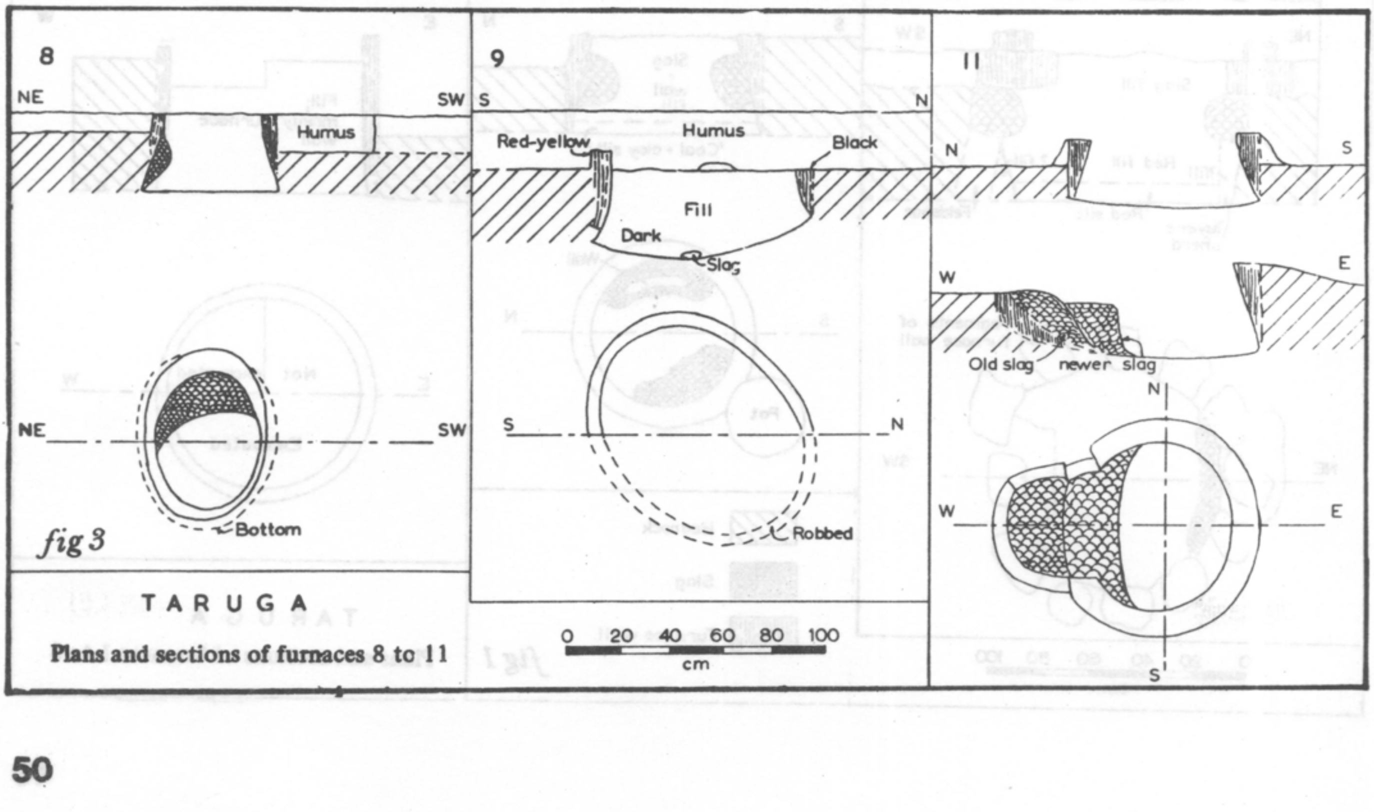
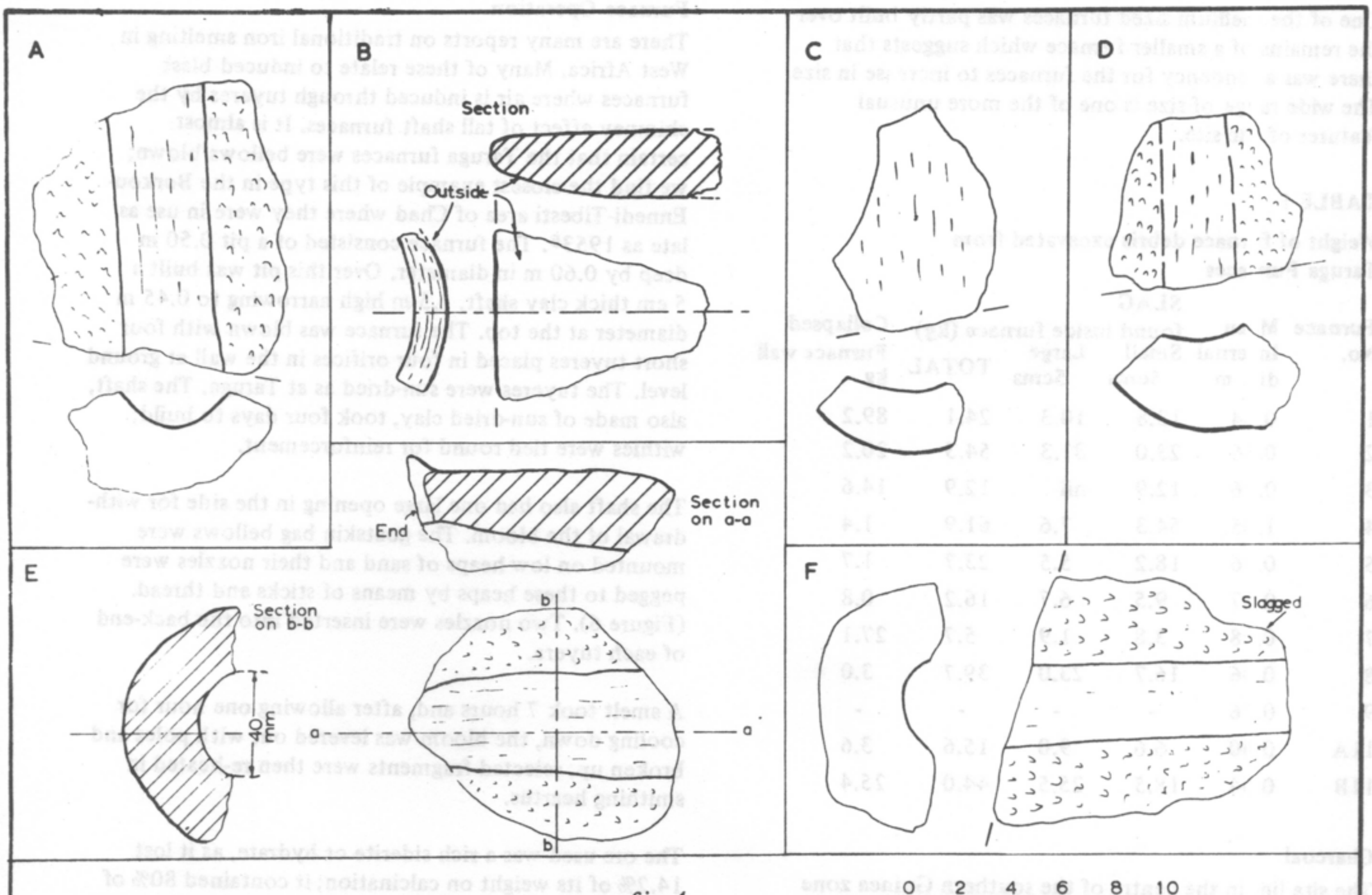


fig 3

TARUGA

Plans and sections of furnaces 8 to 11

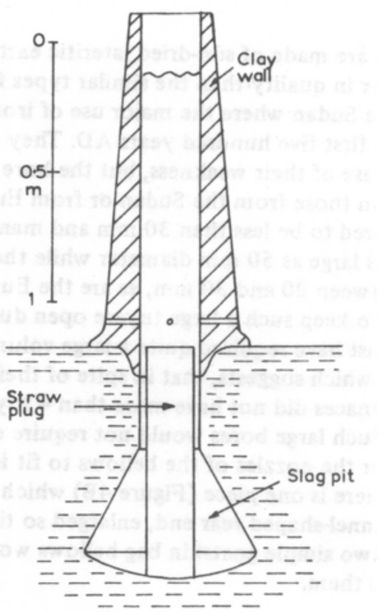


T A R U G A Tuyere sherds *fig 4*

product made by many of the traditional Nigerian smelters during the last 50 years and which had to be worked into a solid piece of metal by breaking it up and welding the individual pieces of iron together. Some old, discarded, saddle querns were found on the site with deep and narrow holes made in them which had probably been used for separating the malleable iron from the brittle slag and charcoal by hammering.

A good deal of slag showed the imprint of cereal stalks. Analogy with the furnaces from Jutland suggests that this arises from the use of a straw plug placed in the top of the pit, (Figure 5) which attains considerable strength after carbonising and which can then hold up the weight of the contents of the furnace until a cetain weight of molten slag is formed. By this means the pit of the furnace is kept empty so as to receive the slag when it has formed. Without the use of the straw plug, charcoal would fill the pit and the slag would be formed so high up as to impede the reduction of the iron ore just above tuyere level. Comparison with the Jutland furnaces must not be taken too far since it is possible that these were blown by induced draught. Furthermore, the diameter of the top of the pit of the furnaces from Jutland was about 24 cms, and it is difficult to believe that the contents of furnaces with a diameter as great as 91 cms can be held up by a carbonised straw plug. It is possible that only the smaller furnaces were worked in this way. None of the furnaces had any provision for slag tapping.

fig 5



Drengsted–Scharmbeck type of furnace from Northern Europe (after Thomsen[4]).

One of the medium sized furnaces was partly built over the remains of a smaller furnace which suggests that there was a tendency for the furnaces to increase in size. The wide range of size is one of the more unusual features of the site.

TABLE 1

Weight of furnace debris excavated from Taruga Furnaces

Furnace No.	Mean Internal dia. m	SLAG found inside furnace (kg) Small 5cms	Large 5cms	TOTAL	Collapsed Furnace wall kg
1	0.84	13.8	10.3	24.1	89.2
2	0.56	23.0	31.3	54.3	20.2
3	0.76	12.9	nil	12.9	14.6
4	1.05	54.3	7.6	61.9	1.4
5	0.36	18.2	5.5	23.7	1.7
6	0.37	9.5	6.7	16.2	0.8
7	0.38	3.8	1.9	5.7	27.1
8	0.46	16.7	23.0	39.7	3.0
9	0.76	-	-	-	-
11A	0.40	6.6	9.0	15.6	3.6
11B	0.64	18.5	25.5	44.0	25.4

Charcoal

The site lies in the centre of the southern Guinea zone and is covered by typical Savannah woodland with rain forest timber in the more densely wooded valleys. There is little doubt that there was always a plentiful supply of timber in this area; local woods were identified in the charcoal found on the site.

Tuyeres

The tuyeres are made of sun-dried lateritic earth and are much poorer in quality than the similar types found at Meroë in the Sudan where the major use of iron working dates to the first five hundred years AD. They are thick-walled because of their weakness, but the bore is rather larger than in those from the Sudan or from Europe. None appeared to be less than 30 mm and many must have been as large as 50 mm diameter while the Sudanese ones are between 20 and 30 mm, as are the European examples. To keep such a large tuyere open during smelting must have required quite a large volume of air per minute which suggests, that in spite of their large size, the furnaces did not have more than 4 tuyeres to a furnace. Such large bores would not require enlarged rear ends for the nozzles of the bellows to fit into. However, there is one piece (Figure 4B) which could be part of a funnel-shaped rear end, enlarged so that the nozzles of two simple goatskin bag bellows would fit loosely into them.

It would appear from experiments that a workable air rate for a 20 mm bore tuyere for a forced blast furnace would be about 300 1/minute, and one such tuyere is sufficient for a furnace of 30 cms diameter. On this basis the smaller furnaces would require one or two tuyeres while the larger would need 4.

Furnace Operation

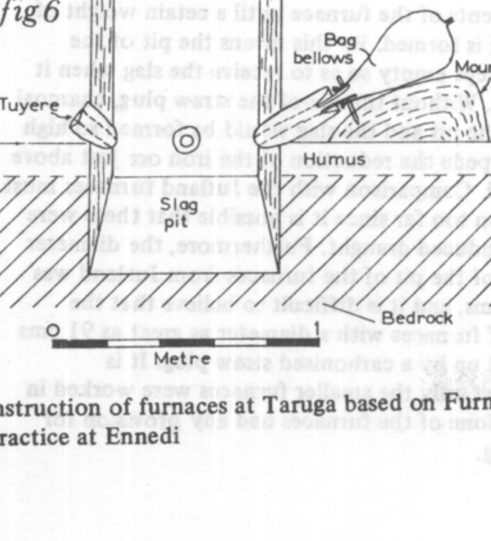
There are many reports on traditional iron smelting in West Africa. Many of these relate to induced blast furnaces where air is induced through tuyeres by the chimney effect of tall shaft furnaces. It is almost certain that the Taruga furnaces were bellows blown; we find the closest example of this type in the Borkou-Ennedi-Tibesti area of Chad where they were in use as late as 1953[5]. The furnace consisted of a pit 0.50 m deep by 0.60 m in diameter. Over this pit was built a 5 cm thick clay shaft, 1.5 m high narrowing to 0.45 m diameter at the top. The furnace was blown with four short tuyeres placed in four orifices in the wall at ground level. The tuyeres were sun-dried as at Taruga. The shaft, also made of sun-dried clay, took four days to build; withies were tied round for reinforcement.

The shaft also had one large opening in the side for withdrawal of the bloom. The goatskin bag bellows were mounted on low heaps of sand and their nozzles were pegged to these heaps by means of sticks and thread. (Figure 6). Two nozzles were inserted into the back-end of each tuyere.

A smelt took 7 hours and, after allowing one hour for cooling down, the bloom was levered out with poles and broken up; selected fragments were then re-heated in smithing hearths.

The ore used was a rich siderite or hydrate, as it lost 14.2% of its weight on calcination; it contained 80% of Fe_2O_3. This loss on roasting would improve the reducibility of the ore but there is no evidence that it was pre-roasted before being charged. Roasting usually takes place in the higher levels of such shaft furnaces.

No mention is made of the diameter of the tuyeres nor of the use of straw to keep the slag pit open. But the short, stumpy nature of the tuyeres shows that they must have been very similar to those from Taruga. However, we do have recent evidence from West Africa of straw plugs being used in an induced blast furnace, with 9–12 tuyeres (1.35 m long.[6] Here the pit 0.9 m deep and was filled with the stalks and chaff of bulrush millet. The tuyeres had been laid at ground level on this mass of straw.



Reconstruction of furnaces at Taruga based on Furnace 2 and practice at Ennedi

Iron Ores

Two types of ore were found at Taruga but only in small amounts (Table 2). The majority (710 g) was limonite i.e. the weathered product of a formerly sideritic mineral. Some pieces appeared to have been weathered to hematite (Fe_2O_3) or goethite (FeO.OH). But in others there was probably a good deal of residual siderite ($FeCO_3$). Some pieces had been heated and oxidized, others had been partly reduced, probably in the furnace. The weathered siderite is typified by Ore 4, Table 2.

The other type of ore (192g) was a hematite similar to that from Kawu some 65 km away (Ore 36, Table 2). This is not a straightforward laterite, which would be of too low a grade, but a hematite formed from laterite by some secondary process. There is a good deal of this type of material in Northern Nigeria such as that near the airfield at Jos, and on Dalla mound at Kano. The analysis of the ore from Jos is given in Table 3. Its lateritic origin is shown by its high alumina content. After roasting, such an ore would have an iron content of 52%. This may be compared with the iron contents of Ores 4 and 36 which have, after roasting, 42 and 65% Fe respectively.

TABLE 2
Analyses of Ores and Slag from Taruga

%	Slag	Ore 36 (hematite)	Ore 4 (limonite)
SiO_2	25.5	2.2	15.7
CaO	1.4	0.28	0.21
FeO	46.7	0.36	0.22
Fe_2O_3	10.7	87.5	49.5
MgO	0.9	1.7	1.1
MnO	2.4	0.58	0.15
Al_2O_3	8.9	0.8	14.5
P_2O_5	1.04	0.24	0.23
S	0.038	0.01	0.014
K_2O	0.61	-	-
Na_2O	0.05	-	-
TiO_2	1.1	0.22	1.23
V_2O_5	0.16	0.10	0.21
Moisture	-	0.68	1.15
CO_2	-	0.10	0.16
Loss on ignition	-	5.4	14.3
Total Fe	44.0	61.2	34.6
Total Fe after roasting		65.3	42.0

The two ores analysed in Table 2 have similar phosphorus contents. An ore with 0.24% P_2O_5 would be expected to produce less than 0.05% P in the metal which is about what we find in Ring C *(vide infra)*.

TABLE 3
Analysis of Lateritic ore from Jos Airport

	Dark Red Hematite[7] %
SiO_2	10.83
Al_2O_3	11.77
Fe_2O_3	68.06
FeO	0.63
MgO	0.01
CaO	0.20
TiO_2	0.24
P_2O_5	0.12
SO_3	tr.
MnO	0.03
Loss on ignition	8.08
Total	99.97
Total Fe	48.15

Dried 2 hrs at 105°C

Analysed by Geological Survey, Kaduna.

Slag

Table 2 also gives the analysis of one of the largest pieces of slag. This contains about 44% Fe and thus is not likely to have been produced from ores containing less than this amount after roasting. If it were not for the fact that Ore 4 was found in Furnace 3 one would not have expected such a poor ore to have formed part of a furnace charge. It seems that rich and lean ores were mixed to give an average charge in excess of 50% resulting in a yield of iron of about 10% of that charged. This yield is very typical of the bloomery process at all times.

The phosphorus content suggests some contribution from the charcoal ash although this is not large considering the large amount of charcoal normally required. It would appear that the trees were being debarked since the bark usually contains much more phosphorus than the wood itself.

Structure of Iron Artifacts

A considerable number of small iron artifacts were found on the site, most of them stratified and therefore of the period of the furnaces. Considering their age they were in extraordinary good condition and it is clear that the soil and climate in this part of Nigeria are favourable to the preservation of iron. The 14 objects examined metallographically are shown in Figure 7, lettered (A) to (O). The positions of the sections is shown in some cases, and detailed descriptions are given below:

(A) Q 18.206 A fine pointed object consisting of coarse-grained ferrite with inter-granular carbide. Hardness 148 (HV 5).

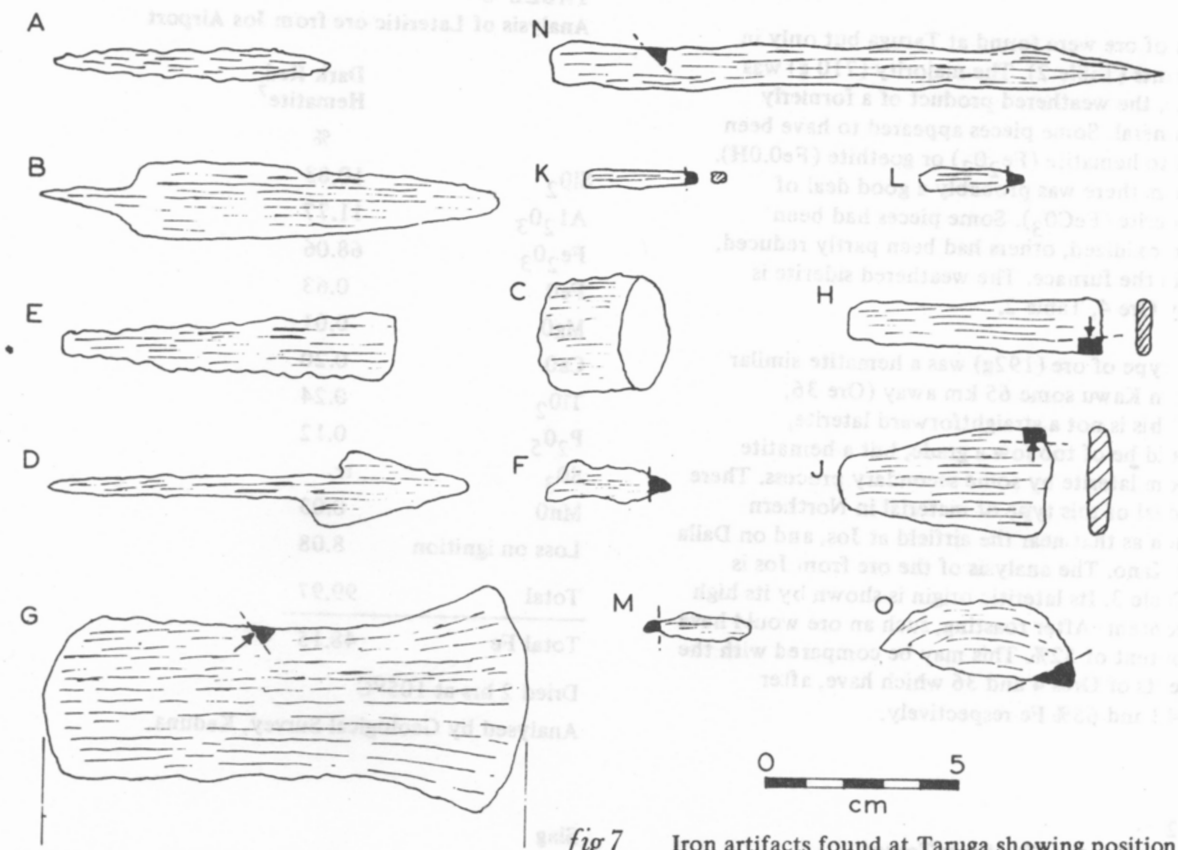


fig 7 Iron artifacts found at Taruga showing position of metallographic specimens.

(B) P 13.2 A knife consisting of equiaxed ferrite with grain-boundary carbide and very little slag. The edge has been cold hammered in order to shape it and the ferrite grains in this area are elongated. No attempt has been made to harden it by carburization. Hardness; back 133, edge 129.

(C) 0 15.a2.1 A ring. This again consists of equiaxed ferrite with grain boundary carbide. In some places the carbide is not completely divorced and shows signs of its pearlitic origin. This contains some slag. Hardness, 137. Analysis gave 0.03% P.

(D) H 15.3 A spearhead. This consists of coarse ferrite with grain boundary carbide. It is extremely clean and does not contain any slag. Hardness, 134.

(E) M 9.1 2 An axe-blade. This also consists of equiaxed ferrite with grain boundary carbide and, like the ring, this also shows its pearlitic origin. In this case the carbon content is probably as high as 0.1%. Hardness, 153.

(F) TA3 N.15.C.2 2 A small fragment from which a specimen was removed at one end. This was examined in cross section and showed a little slag. After etching it was found to consist of a homogeneous carbon steel with about 0.8% carbon. It had had long enough in the range 500–700°C to spheroidise the carbide in the pearlite. The hardness was 265 (HV5).

(G) TA2 AnN 10.3. A very good specimen of a flat axe-head. This was also examined in cross section and consisted of a 0.3% carbon steel with a Widmanstätten structure. This means that it had been cooled fairly fast from a temperature of about 1000°C. As the pearlite was partly spheroidal it must have been held for a short time in the range 500–700°C probably while some final forging was was carried out. The hardness was 180 which is typical for a steel of this type and which suggests that the phosphorus content is fairly low.

(H) TA3 J.13.C.1. 1/2 A piece from a long narrow blade or axe. This was examined in longitudinal section and showed a lot of slag and rust. It was almost entirely iron, not steel, and since it was difficult to etch probably contained some phosphorus. There was some evidence of a grain boundary phosphorus or carbide phase near the surface. The hardness was 143, which is high for pure iron and therefore supports the probability that it contains phosphorus.

(J) TA3 P.22.d.1 2. A piece from a shorter blade or axe head. This was examined in longitudinal section and the disposition of the slag stringers suggested that it was made from three separate pieces of metal welded together. This would mean that the object was made by piling and would in fact consist of many such layers. Etching confirmed the piled nature of the metal. Going from one surface to the other, the first of the three layers consisted of ferrite-and-pearlite with a Widmanstätten structure. The pearlite was coarse and lamellar and the carbon content was 0.3–0.4%. It had been cooled fairly slowly from a high temperature. The next layer consisted of ferrite with marked nitride precipitation. The hardness was about 205 which is extremely high for ferrite – such a hardness and the presence of nitride suggests a high phosphorus content. The third layer had a ferrite-and-pearlite structure but only contained about 0.1% carbon. The pearlite was spheroidised and the hardness about 180, which suggests a small amount of phosphorus.

This object seems to have been made of at least three pieces of iron with different composition. After welding it has been unevenly heated so that different temperatures were reached at various points.

(K) **TA 52. Probably a piece of an awl.** This has a Widmanstätten structure with coarse austenitic grain size. After forging from a high temperature the specimen was reheated perhaps several times so that the interior of the grains have now a veined appearance due to a grain boundary network of spheroidized carbide particles. The mean hardness is 141 HV5 and this suggests that the carbon content is about 0.3%. The steel is clean but no cleaner than those of the first five specimens. It has a very unusual structure. This steel was cooled fairly rapidly from a high temperature; then it was reheated to about 750°C and slow cooled, several times, which re-dissolved the ferrite-pearlite structure in the centre of the Widmanstätten grains and caused it to assume a spheroidised appearance while leaving the ferrite in the original austenite grain boundaries unchanged. This structure was not intentional but arose out of reheating to forge some other part of the artifact.

(L) **Mf.Layer 3 (5) Another piece of an awl.** Mostly oxide. The structure is Widmanstätten, the carbon content about 0.3% and it could well be another bit of the above.

(M) **0 15 a.3c (4) A fragment.** This has a piled structure and either has been made from several pieces of metal or one that has been folded over many times. There is considerable slag or oxide between the layers. It is mostly ferrite with a carbon content between 0 and 0.1% and very fine grain size. It has a slightly Widmanstätten look in places suggesting that it was cooled fairly rapidly from a high temperature and then forged and annealed at a low temperature. The hardness was high (164) suggesting appreciable phosphorus.

Conclusions

The origins of iron smelting at Taruga are obviously either autochthonous or diffused. The fact that the iron industry has not had the benefit of an earlier Bronze Age tradition, and the similarity of the earliest type of furnace with those of Europe suggests that the knowledge of iron working in Nigeria was diffused from elsewhere.

Recent excavations in the Sudan[8] have now shown that the shaft furnaces there at least 500 years later than those from Nigeria and of typical Roman type, whilst the earlier remains of furnaces, dated to perhaps the last centuries BC were much less advanced technologically than those of Taruga.

These facts suggest that we should look to North Africa, and in particular Carthage, for the origins of Nigerian iron working. Unfortunately, little is known about the technique used in and around Carthage from 1000 BC onwards and we can only say that this is the most likely area with the necessary technical level at a sufficiently early date to give rise to a developed iron working technique at Taruga around 400 BC. No actual metal working sites have been found but smelters of iron (and copper) are mentioned on funerary *stelae,* and metal working tools are depicted on some of these at Carthage. The Phoenicians are known to have had trade relations with inland Africa and regular caravan routes existed between the North coast and Nigeria, particularly in the 5th and 4th centuries BC[9]. Other intriguing possibilities suggests themselves such as trade in Nigerian alluvial tin to the Mediterranean. A great deal of work will have to be done on trans-Saharan trade routes to substantiate such possibilities.

The furnaces have some features in common with the Scharmbeck-Drengsted type of Northern Europe which was in use during the first four centuries AD. As at Taruga, they consisted of pits dug in the ground and had thin-walled clay shafts about 1 m high (Figure 5). The pits were kept open with straw. We have very little tuyere material and therefore not much idea as to how they were blown. The recently used furnaces in the Tibesti region of Chad are the nearest modern equivalent to these and there are many examples of the use of straw to keep open the slag pits in Nigeria today. Thus, the tradition is a very long-standing one.

The technique used in the working of the furnaces at Taruga is typical of the EIA in which slag was allowed to run into the pit and was not tapped as was the practice in the more developed types of the Romanized areas of Europe, and in the Suuan.

The crude metal was much contaminated with slag and charcoal and removed in a lump; this was broken up with pestles, in mortars made from old quern stones. The particles of metal recovered from this operation would be welded up, probably by taking a pile of such pieces, wrapping them up in a fireclay envelope and heating them in a forge fire at 1200°C. The enveloped iron would then be taken out of the fire and forged, whereupon the iron pieces would be welded together and the envelope fragmented[10]. This process was seen in use near Jos by Hamo Sassoon in about 1950 and gave very clean iron similar to that from which most of the pieces found at Taruga were made.

Any iron ore with an iron content after roasting exceeding 45% could be worked by this process. The best ores would be the siderites or highly hydrated limonites, but other ores such as hematite could be used if broken fine enough.

Charcoal would have been no problem at Taruga and, at that time as well as in more recent times, the bellows would be blown manually. Production per furnace at Taruga would not be large, perhaps one kg or so per day in the small furnaces and several kg in the larger ones. It is unlikely that smelting was continuous; it was probably carried out periodically to allow the wood and ore to be collected and charcoal to be made.

References

1. B Fagg. World Arch. 1969, 1, 41–50.
2. Thurstan Shaw. Radiocarbon Dating in Nigeria, Ibadan, July, 1968, 116pp.
3. Olvert Voss, Kuml. 1962, p.10.
4. R Thomsen, Kuml, 1963, p.61.
5. L Carl and J Pettit, L'Ethnographie, 1955, (50), 60–81.
6. Angela Fagg, Aspects of the Nok Culture. Conference of W. African Archaeologists, Legon, Ghana, June, 1969.
7. Jos Museum; File on Iron Smelting, TF 92, 1961–67.
8. R F Tylecote, Early Iron Working in the Sudan. Bull. Hist. Met. Group, 1970, 4. 67–72.
9. D Harden. The Phoenicians, London, 1962. pp.147, 164–5.
10. R F Tylecote. Journ. Iron and Steel Inst. 1965, 203, 340–348.

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I am also grateful to Dr R V Riley of the British Steel Corporation at Corby, Northants, for supplying some of analyses.

Materials testing in Classical Greece

TECHNICAL SPECIFICATIONS OF THE 4th CENTURY BC

by George J Varoufakis

Summary

An inscribed stela of the 4th century BC was found at Eleusis in 1893. It cites a decree concerning the manufacture of bronze fittings known as **empolia** and **poloi**, for the erection of the columns of the Philonian Stoa, named after the architect Philo, a portico placed around 360 BC in front of the much older Telestirion. The stela is now in the museum of Eleusis. Its text comprises an order giving the oldest known technical specifications in use in ancient Greece.

The report examines the inscription and evaluates the knowledge and the level of technology involved.

Introduction

The extent of application of technical specifications on manufacturers' purchases and sales of products, raw materials and consumers' goods gives an indication of the technical level of each country. Industrially developed countries use a large number of technical specifications with the aim of securing both quality control of all manufactured products and the possibility of the consumer choosing the best quality product. In contrast in underdeveloped countries specifications are weakly applied in everyday life: consumers are not usually aware of the properties of either the raw materials or the finished products and are, therefore, largely unable to discriminate even if formal specifications are in existence.

The existence and application of technical specifications in the stela under investigation demonstrate the high technical level in technology achieved by the ancient Greeks. In addition, the fact that the inscription constitutes a decree emphasises the importance of the specifications. It also underlines the obligations undertaken by both the supplier of the bronze fittings and an official whom we may describe as the quality control inspector; the first, to carry out the order in accordance with the given specifications and the second, to check the quality of the supplied alloy and any deviation from the given mechanical designations.

It should be noted that there are five other inscriptions related to the erection of the Telestirion portico besides the one under consideration.[1], [2]

Study of the Inscription

D Philios reports in the "Mittheilungen des Deutschen Archaologischen Institutes", 1894, pp 186–189[3], that the stela was found in 1893 at Eleusis among Byzantine ruins. According to the same archaeologist, the height of the stela (figure 1), together with the top projecting cornice, is 51 cm. Its width at the cornice is 29 cm and at the inscribed surface 27 cm at the top and 28 cm at the bottom. The thickness at the cornice is 6 cm and at the remaining part 5 cm. According to Philios the shape of the letters " . . . indicates the early Macedonian age". According to A K Orlandos the inscription belongs to the late 4th century BC[4]

The following is an English translation[4a]:

GODS:[a]

For the shrine at Eleusis: bronze[b] dowels and blocks[c] are to be made for the joints of the column drums in the Portico. For each joint, two blocks and one dowel; the first blocks at the base *[of the column]* are to be six fingers[d] everywhere cubed; the uppermost five fingers everywhere cubed, with the intermediate ones alternating equally between the two sizes. The dowels are to be round, and at the base *[of the column]* five fingers long and two fingers thick, the upper ones one palm[e] long and one and a half fingers thick, with the rest alternating equally in length and thickness between these two extremes. He *[the contractor]* will use copper from Marion, the alloy being made, of twelve parts, eleven of copper to one of tin. He will deliver the blocks clean, rigid and four-square and will round off the dowels on a lathe as in the exemplar provided; he will fix them into the blocks snug, straight and perfectly rounded so that they can be rotated without any deviation. Bids for the contract are to be made at so much per **mina**[f] *[of bronze]* and the contractor will weigh out the bronze while there is constantly present one of the building commission, either the public recorder or the site supervisor. He is to deliver the work without hindering those working on the columns. The accepted bid per **mina**: five and three quarter obols.[g]
The contractor: Blepaios son of So[kl]es from [L]am[ptra [L]am[ptrai].
The guarantor: Kephi[soph]on son of Kephali[onn] from Aphi[i]dne.[h]

(a) Invocation commonly used at the beginning of decrees.

(b) Chalkos can be used to denote "copper" but here must mean "bronze" since the proportions of the alloy are specified below (11. 18–19).

(c) As illustrated in figures 2 and 3.

(d) One dactylos, or finger, was equal to approximately 18 mm.

(e) One palm was equal to four fingers (72 mm).

(f) A mina was equal to 100 drachmae. (Here units of weight, not coinage). Miss Swaddling points out that it seems to have been the normal practice in antiquity for the metal worker to be paid according to the weight of metal worked upon. At Eleusis the would-be contractor had to quote his price 'per **mina**' of bronze.

(g) Left-hand (<) and right-hand (>) "brackets" strokes denoting ½ and ¼ respectively. The price of 5¾ obols per **mina**, Miss Swaddling adds, must refer to labour

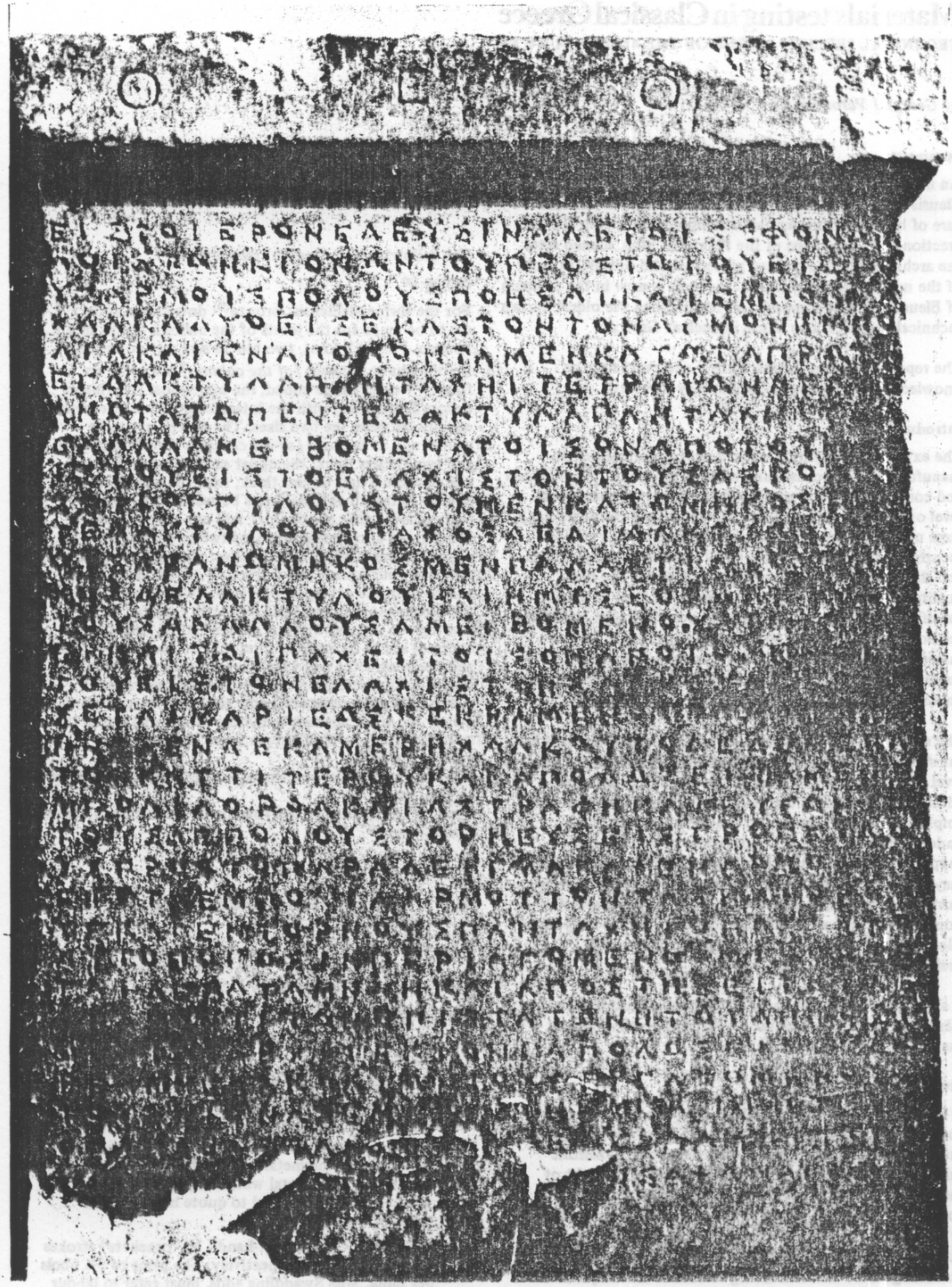

Figure 1 – The stela in the Eleusis Museum

charges alone and not to the bronze alloy which had probably been purchased under a separate contract.

(h) The names in the last two lines were restored by D Philios.

The inscription, which consistitutes a typical form of an offer for tenders based on technical specifications, is examined below under three main heads:

The inscription as a permanent public record,
Structural specifications, and
Chemical specifications.

The inscription as a permanent public record

The inscription appears to consist of two parts, the first being the advertisement for a contractor who would tender for the work which also gives the specifications, and the second part recording the final agreement. The inscription was probably inscribed as a permanent record of the original public notice which was perhaps written on a more perishable material or even given orally. Officials called 'egdoteres' were commonly sent around to announce detail of such contracts. The names in the last two lines would have been added at a later date after tenders had been received, one tender accepted, and the contractor and contract agreed upon.

Structural Specifications

The decree gives an order for the manufacture of empolia and poloi made of copper-tin alloy, i.e. of bronze. The use of this alloy for the assembly of the column drums was new: the conventional material used until then had been hard wood (cedar for the **empolia** and olive tree wood for the **poloi**). The timber was cut down in spring, when the wood had acquired its maximum volume, in order to avoid any further swelling during the wet months. In the 4th century, however, bronze was substituted for wood, probably because experience proved that wood-swelling during the cutting period was not always complete and there was a risk of further swelling during high moisture periods with unfavourable consequences to the solidity of the column structure. Wood has obvious structural weaknesses as a dowel material and it is easily attacked by micro-organisms whose action can lead to its complete destruction. Copper-tin alloys in contrast combine a good corrosion resistance and attractive mechanical properties. Iron and steel are harder than bronze, but they are liable to rust in most environments. Oxidation products, affecting the column drums, could cause damage to the marble. Moreover, the cost of the copper alloy dowels was not very high, compared with the whole project of the Philonian portico. All these advantages of bronze over other materials probably played a decisive role in influencing the builders to use it in the manufacture of the drum fittings. It is not exactly known when bronze began to replace wood in such structures; research, however, shows that in the 4th century BC the use of copper **empolia** and **poloi** was quite common[(5)].

According to our present knowledge, the wooden **empolia** of two successive drums consisted of a pair of symmetrical truncated pyramids opposed at their large bases (figure 2)[(6)]. In the centre of each base there was a round hole of equal length, in order to receive a cylindrical dowel, called **polos**. According to some research workers, **poloi** were only ued for the exact positioning of the drums and, therefore, not for their support. It is possible that **poloi** might play both roles. Future research may prove their exact role. One may speculate that the substitution of wood by the much harder bronze constitutes an evidence of their double role?

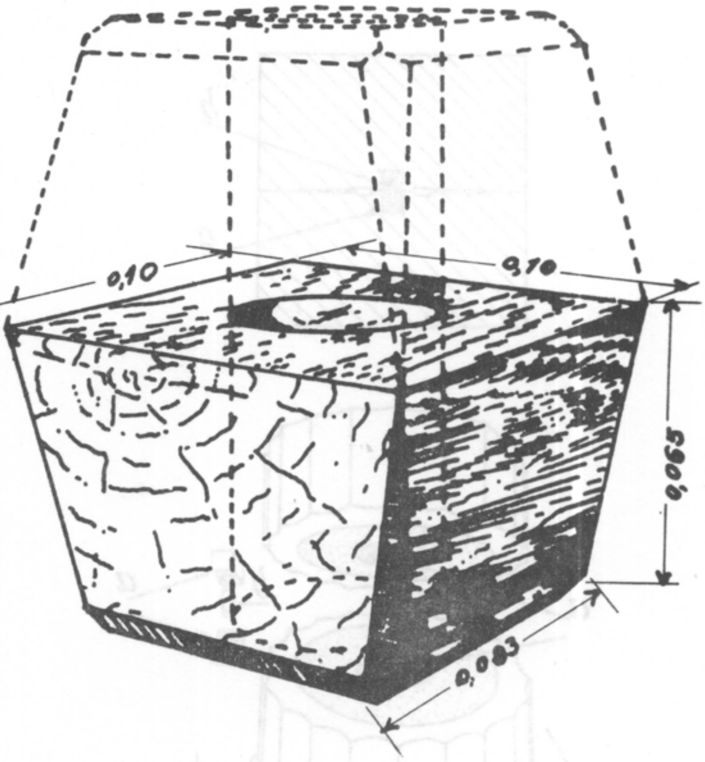

Figure 2 – Wooden **empolia** from Erechtion–Acropolis, in the Acropolis Museum

The inscription gives the manufacturer strict instructions about the shape and the sizes of the **empolia** and **poloi**. Thus it is mentioned that the **empolia** had to be square everywhere with straight edges and right angles, and without any curvature which would not secure a complete fitting in the drum sockets. Figure 3 gives an idea of their shape and their position in the central part of the drum surface at which they touched each other. According to the specifications, the size of the lower empolia should always be 108 mm everywhere and that of the upper ones 90 mm everywhere. The emphasis given by repeating the word "everywhere", underlines the importance for the manufacturer of maintaining an accurate square shape.

The inscription gives further dimensions of the cylindrical **poloi**, which would be inserted into the corresponding holes of the empolia. Thus **poloi** belonging to the lower **empolia** should have a diameter of 36 mm and a length of 90 mm, and those of the upper ones should have a diameter of 27 mm and a length of 72 mm. Dimensions of the **empolia** holes to accommodate the cylindrical **poloi** are not mentioned; it is not difficult to calculate them approximately on the basis of the dimensions of the **poloi** (vide inf.).

Another significant point is the use of the lathe for the shaping of the hard copper-tin alloy into the cylindrical **poloi** according to a given sample. It is stated that they should be machined in such a way that their section is everywhere completely round. The same instruction applied to the holes of the empolia, whose diameter should be slightly larger than that of poloi, in order to achieve a complete and accurate fitting between them and to secure a safe assembly of the columns.

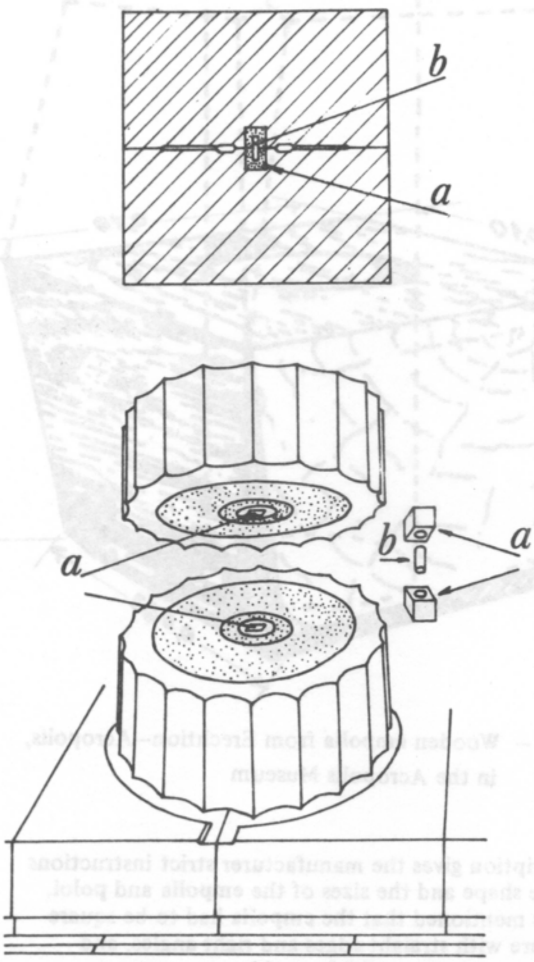

Figure 3 – Drums of a column with their empolia and poloi
a = empolion b = polos

The lathe is known much earlier, but only for the shaping of wood. Homer mentions it several times and words like "tornevo" (to machine on the lathe), "tornos" (lathe) are very common in classical literature. However, the shaping of wood and hard bronze are two completely different things as far as their mechanical properties are concerned. Ancient metalworkers would have to use a cutting tool much harder than bronze, and it is only hard and heat treated steel that could meet this requirement successfully. Furthermore, heat treating of steel presupposes a deep knowledge and a long experience in metalworking. It demonstrates the high technical standards achieved in classical Greece in this field. It is only when hard steel was employed in the making of cutting tools that the lathe took its place in the history of metals. Although this took place probably before the 4th century, nevertheless the inscription of Eleusis constitutes the oldest evidence for the use of the lathe in metalworking in the Greek mainland and it is therefore a fact of considerable importance in the history of metals.

As far as the empolia holes are concerned, it seems that they existed already in the as cast cubical blocks of empolia and they were machined on the lathe to the required final diameters and depths. The possibility exists that the empolia were cast sound, i.e. without the holes and produced afterwards on the lathe, but this procedure is improbable, if one considers the primitive mechanical means available.

Chemical Specifications

The order gives the contractor of the project strict instructions about the origin and the chemical composition of the copper-tin alloy. " .... The copper should be from Marion and contain eleven parts of copper and one part of tin ..." This appears to mean that the copper intended for the manufacture of empolia and poloi should be imported from the copper workshops of Marion, in the North-West region of Cyprus and that the alloy should contain an equivalent (in modern terms) of 91.67% of copper and 8.33% of tin.

The preference for Cyprian copper was due to its excellent quality. Cyprus had been well known since the Minoan and Mycenaean age for the purity of the metal, in contrast to copper imported from Anatolia and the Middle East, which contained impurities, such as silver, gold, lead, zinc, cobalt and arsenic, in small or large amounts. This difference sometimes helps the research worker to identify the origin of ancient copper objects.

In the case of empolia and poloi it is probable that the raw cast metal was imported from Cyprus, and worked in Greece according to the specifications.

Two points of interest attract our attention in these chemical specifications:

the composition of the copper alloy expressed on the basis of the number 12, and

the demand for a specific copper and tin content.

The Number 12

The Babylonians had been using the number 60 as the basis of their calculations since the second millennium BC, possibly even earlier. Little is known about the achievements of the Babylonians in mathematics in prehistoric times until the Persian age[(6a)]. It seems, however, that they had developed to a considerable degree arithmetic, geometry and the algebraic method of solving many problems. It is known that the Sumerians could solve systems with two or more unknown factors. Texts of the later Babylonian period show that the art continued intensely after the 6th century BC. The rapid development of Babylonian astronomy began during the 5th and 4th centuries BC, and became the main carrier of Babylonian arithmetical methods over the world. Even today the key number 60 is in use in many activities of our everyday life; the year has 12 months, the day has 24 hours, the hour 60 minutes, the minute 60 seconds and angles are measured by degrees based on 60. On the other hand we use number 12 very often as a sub-multiple of 60, without sometimes realizing its origin. We ask for example, for a dozen of bottles, books or other objects, and not for ten according to the existing decimal system.

It is concluded that it is possible that the chemical composition of the empolia and poloi is expressed on the basis of the Babylonian arithmetical system, since the number 12 is a sub-multiple of 60. Further research may throw more light on this hypothesis.

Alloy Composition

The requirements concerning alloy composition again give evidence of the deep knowledge possessed by the ancient Greeks in the field of the then known metals and their alloys in so far as their composition allied with their mechanical properties was concerned.

Research carried out on Mycenaean weapons and implements of the 16th century BC has shown that metallurgists of that remote time were experienced in the relation between the mechanical properties of copper alloys and their tin content. It is well known that tin increases hardness and strength of these alloys and at the same time improves their casting properties.

Spearheads, sword blades, daggers, knives and other weapons always consisted of copper tin alloys sometimes forged cold. Metalworkers could achieve successfully in each case the required mechanical properties by casting the right alloy composition, and forging it hot or cold to a certain degree. On the other hand rivets fixing the hilt on to the blade of a sword or a dagger consisted of unalloyed copper. Any foreign element found, is to be considered as an impurity originating from raw materials and not as an intentional addition. This almost clean copper was therefore soft enough to be forged cold without serious difficulty so far as it was necessary to shape their ends into the flat heads of a rivet, and secure a solid and safe fixing between hilt and blade.

There is evidence, therefore, that even in the second millennium metallurgists knew how to choose successfully the right metal or alloy.

In my research paper "Metallurgical Research on Copper Objects from Tomb B at Mycenae",[7] although I did not know at that time of the existence of the Eleusian inscription, I drew attention to this aspect:

"... Probably they would apply a kind of empirical test on metals and their alloys in order to choose the quality required each time, and on the other hand to evaluate them in their commercial transactions. In other words there should be some kind of specifications on which buying and selling of metals was based ..."

I arrived at this conclusion following the results of the above research work, and of a further study "On metallic objects found at the Mycenaean Cemetery of Perati, of the 12th century BC[8]. Research studies of other scholars in various areas of the Middle and the Near East, and Central and Western Europe reinforced my view. It is reasonable to assume that metalworkers of the 4th century BC had an experience of more than two millennia as far as composition in relation to mechanical properties was concerned, and it is not accidental that the Eleusian inscription insists on a certain copper-tin composition.

Quality Control

A highly important question to ask is how would the contractor or the inspector check whether the bronze composition was according to the requirements of the specifications, in other words, was there any quality control test? The answer is not simple, since we have no evidence so far of any quality control upon delivery. Nevertheless, the fact that metalworkers knew in advance the mechanical properties of the alloys in connection with their composition, and above all, the discovery of the inscription placing an order with a copper workshop on the basis of definite specifications, favours the point of view that there existed a kind of quality control. In fact the chemical specifications given by the decree would be of no value if there did not exist some control over both the quality and the product and the degree to which a supplier might deviate from his legal requirements. It should be noted that according to an inscription from the Hephaestion of 420 BC in the Atherian Agora[9] the price of copper was less than 35 drachmas per talent[9a] (a talent was equal to approximately 26 Kg). The price of tin was 230 drs per talent, i.e. over 6.5 times higher than that of copper. The supplier would therefore be inclined to cast a poorer and consequently a cheaper, and for him more profitable, copper-tin if he knew that no control existed.

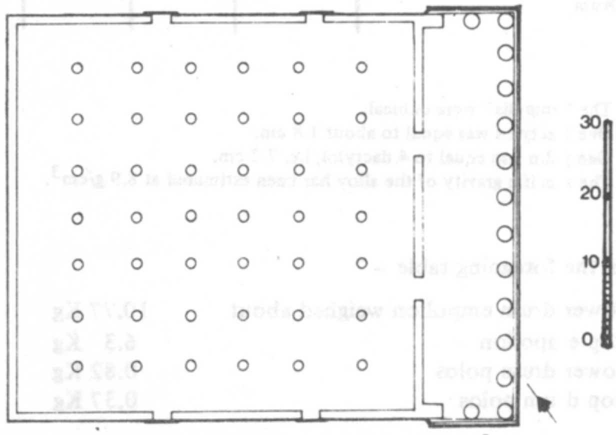

Figure 4 — Plan of the Telestirion and the 14 columns of the Philonian Stoa (after J N Travlos)

Weight and Value of the Bronze Empolia and Poloi

As illustrated in Figure 4 the Portico columns of the Telestirion were fourteen and according to Noack each consisted of ten drums. This means that eleven pairs of **empolia** and eleven **poloi** were required for the assembly and support of each column, since each joint required two **empolia** and one **polos** (see Figure 3). Of these, ten pairs of **empolia** and their **poloi** belonged to nine drums, while the eleventh pair and its **polos** were located between the top tenth drum of the column and the capital. It should be remembered that a pair of **empolia** and a **polos** were located between the column bases and the first drum. The total number, therefore, of the **empolia** and **poloi** of the fourteen columns of the Philonian Stoa was:

Empolia : 280 pieces for the lower drums, and 28 pieces for the upper drums

Poloi : 140 pieces for the lower drums, and 14 pieces for the upper drums.

To calculate their weight the inscription gives the sizes of the **empolia** and **poloi**, but it does not mention the sizes of the **empolia** holes into which the **poloi** were fitted, and the specific gravity of the alloy is unknown. The calculations below are given not to estimate the weight of the bronze fittings but to emphasise both the importance of the existence of quality control in antiquity as well as the large margins of profit in case of some illegality on the part of the supplier. To this purpose the following table shows the sizes and the calculated weights of **empolia** and **poloi** on the basis that the specific gravity of the alloy was equal to $8.9 g/cm^3$ and the sizes of the **empolia** holes a little larger than the corresponding **poloi**:

TABLE OF "EMPOLIA" AND "POLOI" SIZES AND WEIGHTS

	Empolion Edges in dactyloi and centimetres (1)		Empolion Hole Diameter	Empolion Hole Depth	Empolion Hole Volume	Polos Diameter		Polos Length		Empolion Net Volume	Polos Volume	Empolion Weight (4)	Polos Weight (4)
	Dact. (2)	cm	cm	cm	cm^3	Dact.	cm	Dact.	cm	cm^3	cm^3	(g)	(g)
Lower Drum Empolion	6	10.8	3.7	4.6	49.45					1210.26		10771.31	
Top Drum Empolion	5	9	2.8	3.7	22.75					706.25		6285.62	
Lower Drum Polos						2	3.6	5	9		91.62		815.41
Top Drum Polos						1.5	2.7	(3) 4 (One Palm)	7.2		41.18		866.5

(1) The "empolia" were cubical.
(2) One Dactylos was equal to about 1.8 cm.
(3) One palm was equal to 4 dactyloi, i.e. 7.2 cm.
(4) The specific gravity of the alloy has been estimated at 8.9 g/cm^3.

From the foregoing table –

the lower drum empolion weighed about	10.77 Kg
the top empolion	6.3 Kg
the lower drum polos	0.82 Kg
the top drum polos	0.37 Kg

Therefore, the total weight of the bronze fittings would be:–

1. Empolia of the lower drums
   280 pieces x 10.77 Kg = 3,015.6 Kg
2. Empolia of the top drums
   28 pieces x 6.3 Kg = 176.4 Kg
3. Poloi of the lower drums
   140 pieces x 0.82 Kg = 114.8 Kg
4. Poloi of the top drums
   14 pieces x 0.37 Kg = 5.18 Kg

Total Weight = 3,311.98 Kg

or about 3,300 Kg.

Considering that the weight of one talent was about 26Kg, then the weight would be about 127 talents. Taking into account that the tin content of the bronze amounted to 8.33%, the weight of this metal, contained in the alloy would be: 127 talents x 0.0833 = 10.57 talents. The price quoted in the Hephaestion inscription of the 5th century BC is likely to be less than 35 drs per talent for copper since that price is given for bronze and 230 drs per talent for tin. The cost, therefore, of tin as a raw material would amount to at least:

10.57 talents x 230 drs = 2,431 drs

and that of copper:

116.43 talents x 35 drs = 4,075 drs

Total Cost = 6,506 drs

Of course, prices quoted in the 5th century BC inscription might be different from those of the 4th century; however, the price difference between the two metals would be great, if not greater, and, as already mentioned, prices in the inscription have been used in the above calculations to point out the large margins of profit in case of adulteration. Thus, in spite of the relatively small tin content (8.33%), this metal represented 37% of the total value of the alloy, and profits from a decrease of the tin content would undoubtedly be considerable. It is calculated that if the supplier decreased the tin content by 2–3% the total value of the raw material before casting would amount to 6,010 drs and 5,763 drs, respectively, and his profit would be 500 drs and 740 drs in each case. If the price of copper was, say, 33 drs as might be inferred from the Hephaestion inscription and not 35, the increases in profits would be even greater. These sums are very high for the time and it strengthens the hypothesis of the existence of quality control.

Inspection

Another important question is to find how an inspector could check whether the bronze fittings composition met the requirements of the specifications. I assume that the control was based on empirical methods, since chemical analysis or any other scientific test is out of the question.

An assumption is that a very experienced eye could identify the composition of a polished copper alloy specimen on the basis of its colour. The tin content of bronze seldom exceeds 15–18%. If, therefore, the official in charge of quality control had a set of polished copper-tin alloy specimens of known composition, he could approximately classify the unknown alloy by comparing it with this set of standards. If the tin content had to be 10% and the alloy contained 9% or 11%, it would be rather difficult for him to distinguish the colour difference. But if the tin content was less than 6%, then the colour would clearly reveal that its composition was outside the specification and the alloy would be turned down. In any case a difference of less than two per cent should not be considered as intentional, but rather as a failure during the metallurgical process of mixing copper and tin or of a an unpredictable oxidation of one of its components, due to the primitive and uncontrollable casting techniques applied at that time. In the particular case of the inscription, the inspector's main concern would be the detection

of any intentional deviation of more than 2% below the specified tin content and this for two reasons:
the bronze would be softer and its mechanical properties deficient for the given structural purposes, and
any negative deviation would prove the existence of an illegitimate profit on the part of the supplier.

To strengthen the above assumption, I carried out an experiment by casting small bronze specimens whose tin content ranged from 0 to 13%. I noticed that a distinct colour difference existed between two specimens when their tin content differed by 2%, and I realised the possibility of applying this test to classify a bronze of an unknown composition. 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.

Qualitative hardness test could be another possible test of the copper-tin 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 would be realised on a comparison basis, as in the above mentioned case of colour matching test, yet a qualified quality control man could identify the alloy hardness just by using a file, as is the case, nowadays, in small workshops, which do not possess hardness testers and other laboratory facilities.

Specific gravity determination could not constitute a practical way of testing bronzes even if buoyancy of solids in water, discovered by Archimedes, was known in those days, because there is no substantial difference between specific gravities of copper and its alloys. On the contrary, gold and its alloys can be distinguished approximately by determining their specific gravities, because of the existing great difference beween the specific gravity of gold (19.3g/cm^3) and that of copper (8.92g/cm^3) and silver (10.5g/cm^3)[(10)]. This difference helped Archimedes to find out that the wreath of Jeron, Tyrant of Syracuse, was made of a gold-silver alloy and not of pure gold as it should have been.

Mr Morris Pearl has pointed out to me that a further possibility exists for controlling the composition. It was common practice in antiquity for the metalworker to be paid according to the weight of metal which he worked, as may be seen from Diocletian's Edict whereby Roman coppersmiths were paid by the weight of copper. Similarly, metallurgical controls may have been exercised before melting. One may speculate that controls existed at the furnace and that publicly weighed quantities of copper and tin were charged in the furnace in the presence of officials to produce an alloy which, even with some losses of metals, would give a product close to the desired chemical composition and mechanical properties.

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

Conclusions

The inscription under consideration belongs to the 4th century BC and contains a decree stating technical specifications for the manufacture of bronze fittings (empolia and poloi) connecting the drums of the Philonian Stoa colums. The stela is kept in the Museum of Eleusis and constitutes a discovery of exceptional importance, because it demonstrates the high standard of ancient Greek technology in the field of metallurgy and refers to the oldest Greek bronze specifications known.

The study examines the inscription in the light of historical metallurgy in an effort to assess the technical knowledge of Greek metalworkers in the making and testing of metals and their alloys.

It is concluded that Greek metallurgists in antiquity were aware of the mechanical properties of copper alloys in connection with their composition, and in particular their tin content.

Some kind of quality control system was in existence, otherwise the given chemical specification would be of no value. The study describes probable ways of checking the alloy composition. To emphasize the necessity of quality control the approximate total weight of copper and tin, contained in the alloy, and the corresponding value of each of these metals are calculated, showing the possibility of a large margin of profit in the event of illegal adulteration on the part of the supplier.

ACKNOWLEDGEMENTS

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Thanks are also due to Miss Judith Swaddling of University College London, for much help in the translation of the inscription and in its interpretation.

References

1. **American Journal of Archaeology**, 1905, 9, 147.
2. G E Mylonas, "**Eleusis and the Eleusinian Mysteries**" Princeton University Press, 1961, F Noack, "**Eleusis**", 2 vols. Berlin. 1927.
3. D Philios, **Mittheilugen des Deutschen Archaeologischen Institutes** 1894, 186–189.
4. A K Orlandos, "**The Construction Materials of the Ancient Greeks**". 1955.

4a For help in the translation into English of the inscription and for information about its dual characterstics of advertisement for tender and accepted bid grateful acknowledgement is made to Miss Judith Swaddling of University College London.

5. Rolland Martin, "**Manuel d'Architecture Grecque**", Edition A & J Picard & Cie, Paris, 1965.
6. Allan Marquand, "**Greek Architecture**", Macmillan Co., New York, 1909.

6a Herodotus, Book II, 109; Kurt Vogel, Vorgriechische Mathematik, II, 1959, p15; M Cantor, Vorlesugen uber Gesicht der Mathematik, I, 1965, p47; Th. Heath, Greek Mathematics, I, 1921, Oxford, 28–29.

7. G J Varoufakis, "**Metallurgical Research on Copper Objects from Grave Circle B of Mycenae**"; Appendix of G E Mylonas' book "**The Grave Circle B of Mycenae**"
8. G J Varoufakis, "**Examination of Metallic Objects from Perati**" *Archaeologiki Ephimeris*, 1967, p70–82.
9. **Inscriptiones Graecae**: IG 318–319; IGI^2 370–371.

9a The price of copper was probably less than 35 drs. Miss Swaddling who is studying the Hephaestion inscription in work for her PhD thesis believes that the cited price is for bronze not copper: the alloy would have been more expensive than the metal.

10. Earle R Caley, "**Validity of the Specific Gravity Method for the Determination of the Fineness of Gold Objects**" *The Ohio Journal of Science*, March 1949, 49(2).

Copper artefacts from Tutankhamun's tomb

by H H Coghlan, FSA, FMA

In 1936, the Borough of Newbury Museum was presented by Mr A Lucas, OBE, of the Cairo Museum, with three small copper objects. Museum number 1936–8. These are described as model agricultural implements, and come from the tomb of Tutankhamun, Luxor, Valley of the Kings. The opportunity has now been taken to examine these artefacts which are illustrated in Figure 1, A to C.

It does not seem possible to determine what kind of agricultural implements the specimens in the Newbury Museum may represent. However, Dr George Parker has suggested that these specimens were catalogued as miniature agricultural tools and indeed were found in an appropriate context, that is, with the funerary statuettes called Shawabti figures whose function was to answer for, and then to work instead of the pharaoh when he was called to do such menial tasks as agricultural labour in his after life. It will also be remembered that the tomb contained some very small models of tools made of iron, the largest being only about on third of an inch in width, and only one inch in length.

As a matter of convenience the three specimens have been designated by the letters A, B and C. For the purpose of analysis and metallographic examination specimen A was selected. Two small pieces of about 7 mm in length were removed from each end of the specimen (mount 62), and two positions, at 56 mm apart, were selected for analyses. These positions should be representative of the copper as a whole. The copper wire which, as received, was found wrapped around specimen C, was also examined both in longitudinal and cross sections (mount 61).

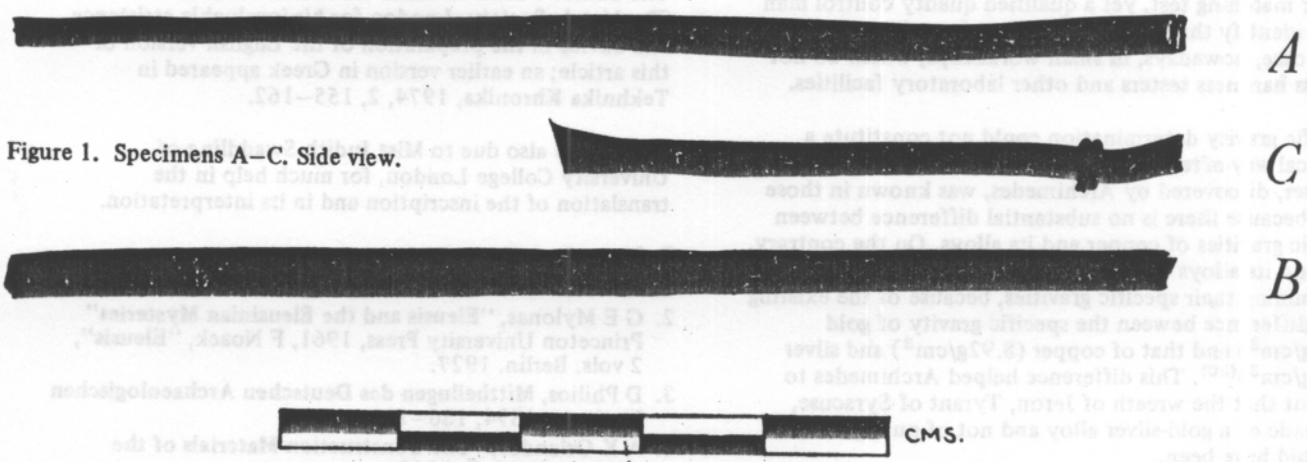

Figure 1. Specimens A–C. Side view.

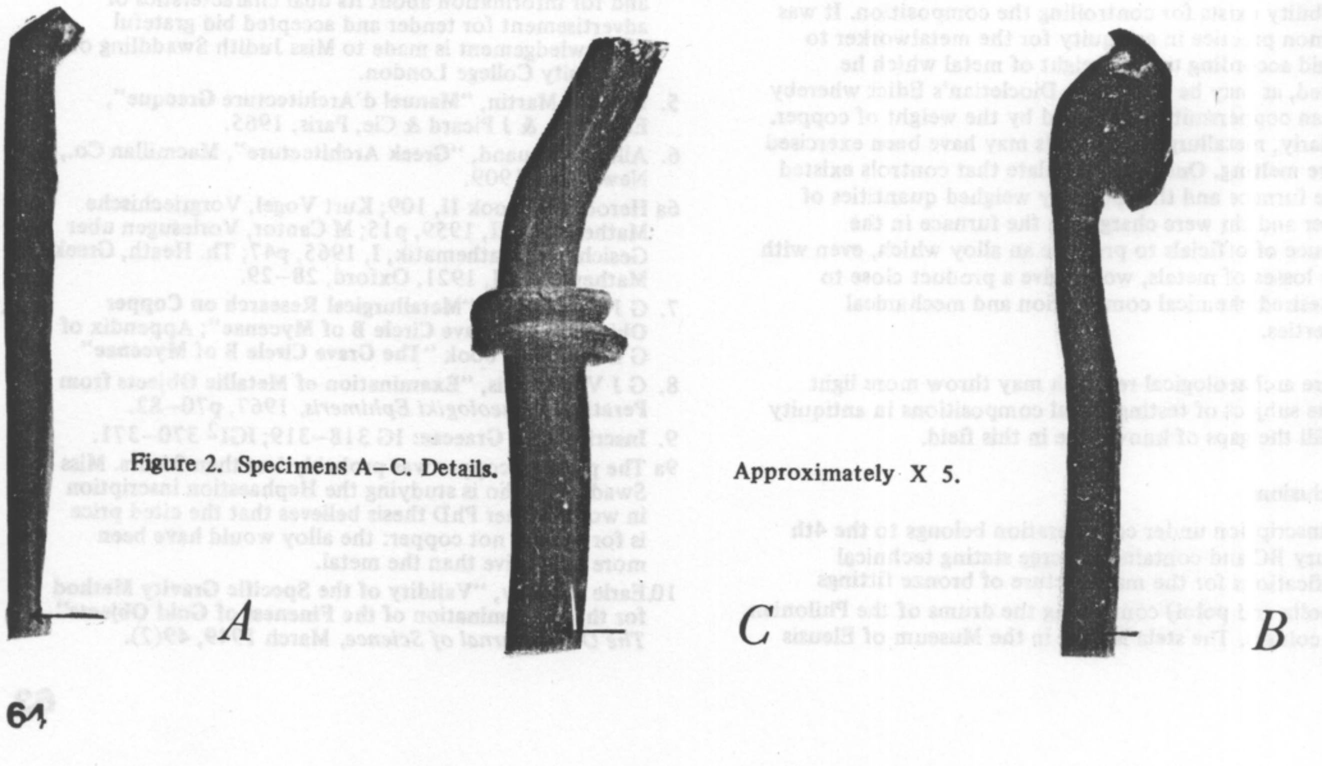

Figure 2. Specimens A–C. Details. **Approximately X 5.**

SPECIMEN A (Figure 1 A)

The patination of this specimen is of dark coppery colour, smooth and regular; under visual inspection there is no evidence of corrosion attack. Longitudinal striations showing in the patination suggest that the implement had been finally smoothed by grinding with a coarse gritted stone or hone. Clearly, it was intended to bend round one end of the metal so as to form a loop or eye, but the metal fractured before bending had reached an angle of 90°. (Figure 2 A). The fracture is coarse and laminated, possibly the metal was overheated at this point during fabrication. The other end of the specimen has also been fractured; here, two chisel cuts close to the fracture suggest that the copper was notched and then broken off. From the end which has been partially bent round, and over about half of the length of the specimen, the copper has been forged to a rectangular section (about 3.2 x 1.2 mm), while the remainder of the piece has been roughly forged to an approximately circular section of 2.10 – 2.15 mm. The forging or hammering is irregular, and little attention has been paid to accurate finishing. The total length of specimen A is 95 mm. Approximate weight 3.5 grammes.

The composition of the metal, expressed in percentage figures, is given below.

	Position 1	Position 2
Au	nd	nd, prob<0.001 if any
Sb	0.003	0.003
As	0.1	0.1
Bi	0.0004	0.0004
Co	0.003	0.003
Fe	~0.05	~0.05
Pb	0.01	0.01
P	nd	nd <0.005 if any
Si	nd	nd<0.01 if any
Mn	nd	nd<0.01 if any
Ni	0.02	0.02
Ag	0.001	0.001
Sn	>0.5	>0.5
Zn	nd	nd 0.001 if any
Tl	0.005	0.005
Al	nd	nd<0.001 if any
Mg	nd	nd<0.001 if any

nd = not detected. ~ = approximately.
< = less than > = more than.

From the analytical figures it will be seen that the material is a high purity copper, with the exception that the tin content is more than 0.5 per cent. The total of minor or trace element impurities do not exceed about 0.2 per cent. For Egyptian coppers, such purity would appear to be not unusual as shown by a number of analyses published by A Lucas in his book "Ancient Egyptian Materials and Industries", 1948, 542–3.

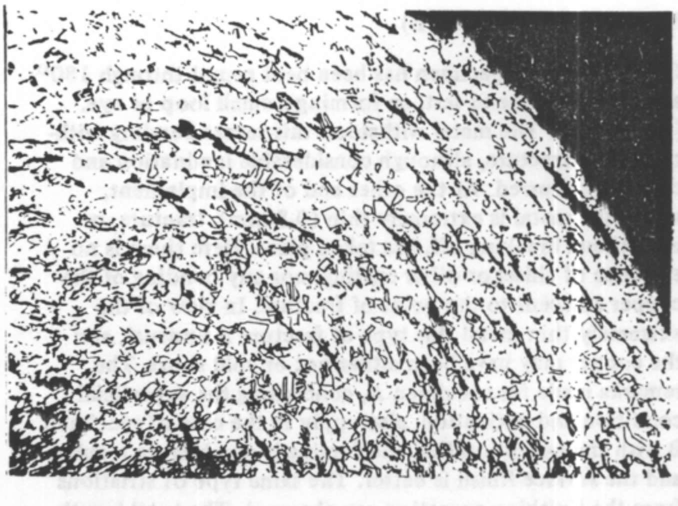

Figure 3. Specimen A. Non-metallic inclusions which have been bent round following the attempted formation of the loop or eye. X 50. Etched.

Upon examination of the polished but unetched sections (mount 62), it was seen that the metal is not clean, containing dove-grey non-metallic inclusions which are probably of slaggy origin. These inclusions are elongated in a longitudinal direction, probably as a result of hot working. Unexpectedly, cuprous oxide was not detected in the specimens which indicates deoxidation of the copper; since tin acts as a deoxidizing agent this is probably due to the presence of more than 0.5 per cent of tin in the material, but there is also the possibility that a measure of primitive 'poling' was resorted to in the melting stage. Upon etching the sections show a structure of equi-axed twinned crystals of low grain size. The material has been given a low temperature anneal after forging, no slip bands were observed in the microstructure and the copper has apparently been left in the soft, or semi-soft, annealed state. Figures 3 and 4.

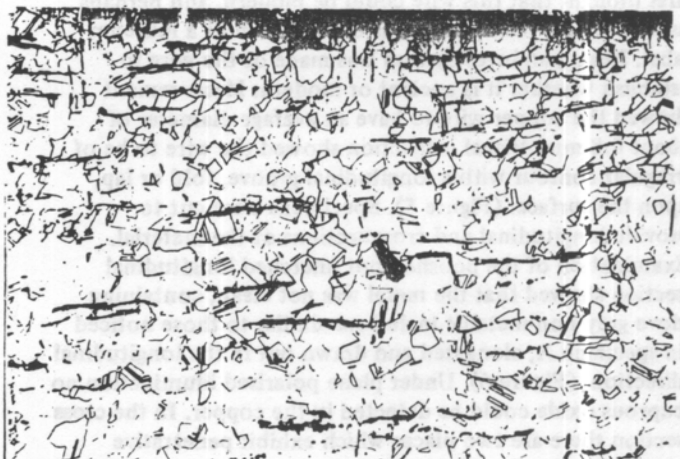

Figure 4. Specimen A. The general structure of equi-axed twinned crystals of low grain size, and non-metallic inclusions elongated in the direction of forging. X 100 Etched.

SPECIMEN B (Figure 1 B)

One end of this specimen has been bent round through 180^{o}, as in a modern bend test, so forming a small loop or eye. (Figure 2 B). The metal withstood this severe bending without actual fracture, although considerable lamination and cracking occurred. At the other end of the implement, where the metal is extremely thin (0.8 mm), fracture, or intentional breaking off, has taken place. Here there is no evidence of chisel or other cutting, nor any bending of the copper adjacent to the point of fracture. In view of the extremely thin metal this type of fracture is unusual, and the copper may have been either hot or cold short. The remarks made for specimen A, concerning the superficial condition and patination, also apply in the case of specimen B with the exception that the forging is much more regular, and the surface finish is better. The same type of striations from the finishing operation are observed. The total length of the specimen is 95 mm the same as that of specimen A. At the loop end, the metal is 1.25 mm in thickness with a width of 3.5 mm, at the other, fractured end, the section is 0.8 mm in thickness and 4 mm in width. Weight 3 grammes.

SPECIMEN C (Figure 1 C)

This piece is quite distinct from specimens A and B, it is much smaller and of different shape. At one end of the specimen the metal has been strongly flaired out to one side, and cut off at a pronounced angle to the longitudinal axis (this is a feature noticed in one of the miniature iron tools which were also found in the tomb). At the other end, the metal has been bent and then apparently cut off with a tool of some kind. There is no evidence of bending at the point of cutting or fracture. The surface finish and patination are similar to that of the other two specimens. The total length is 51 mm, and the cross section of the metal is approximately 1.25 mm in thickness and the width over most of the length is 3 mm. Weight 1.5 grammes.

An interesting feature of this specimen is the two coils of copper wire which were found wrapped round the object, when received in the Newbury Museum. (Figure 2 C). It was first thought that this wire could be modern, and perhaps used for some such purpose as the tying on of a museum label. Hence, an investigation was made of the wire to establish whether it is ancient or modern. Measurement showed the copper wire to have an average diameter of about 0.8 mm. Visual inspection showed the wire to be of irregular contour with a longitudinal groove, fold or lap, upon the surface. (Figure 5). Specimens were cut to provide longitudinal and cross sections of the material. Examination of the polished but unetched longitudinal section showed that the metal was not clean, containing dove grey non-metallic inclusions similar to those noticed in specimen A, elongated and drawn out in the longitudinal direction. (Figure 6). Under plane polarised illumination no cuprous oxide could be detected in the copper. In the cross section there are two places which exhibit penetrative corrosion attack, and this corrosion would appear to be of ancient origin. The irregularity in contour, and pronounced folding or grooving, certainly do not suggest the probability of the wire having been drawn through a modern die.

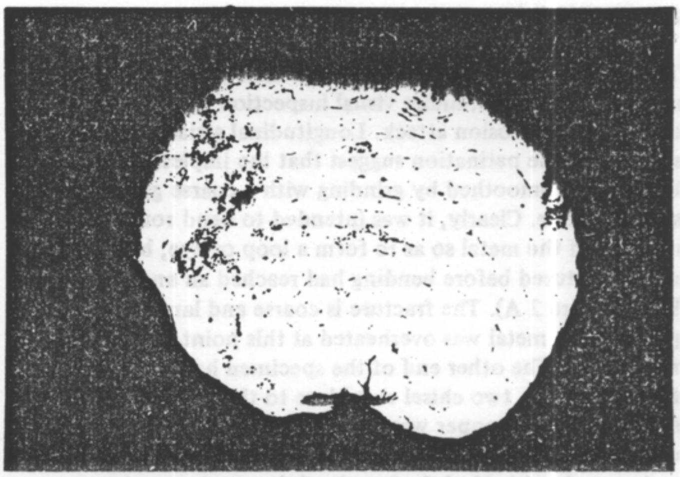

Figure 5. Showing the irregular contour of the cross section of the copper wire. X 50. Unetched.

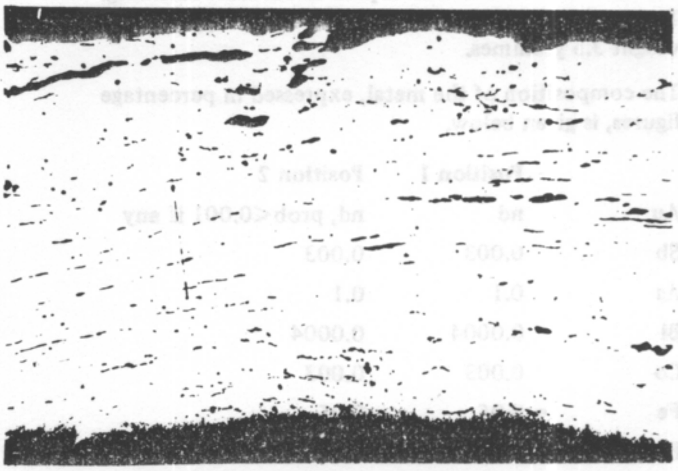

Figure 6. Non-metallic inclusions in the copper wire which are drawn out in the direction of forging. X 50. Unetched.

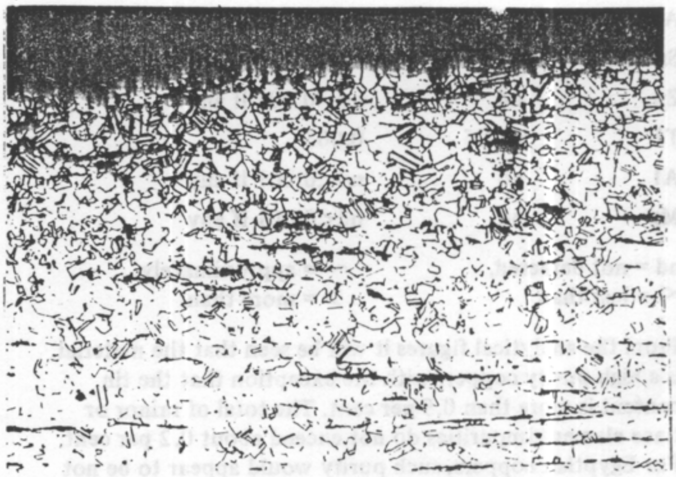

Figure 7. Copper wire. The structure of equi-axed twinned crystals of very low grain size. X 100. Etched.

Upon etching both longitudinal and cross sections show a structure of equiaxed twinned crystals of small grain size, coring was not observed, and the metal has been homogenised. Slip banding was not seen in the crystals, so the metal has apparently been left substantially in the annealed state. (Figure 7). Dr George Parker kindly commented upon some unexpected features of the wire. He would expect to see cuprous oxide inclusions in ancient copper wire, but mentions the possibility that the copper wire was 'overpoled' just to the point that no cuprous oxide was left, so that it is in effect a primitive form of the modern oxygen free high conductivity copper. Also, remembering that the tomb was cleared in the years after 1922, it would be expected that any modern wire would be much cleaner, i.e. virtually clear of inclusions. The result of the examination shows that the wire which was found with specimen C is in fact of ancient origin, and most likely to be contemporaneous with the specimen. No explanation can be offered for the presence of the wire, or of what its function was.

In conclusion, we may say that it is clear that the objects are not in any way working tools, and they would have no practical value as such. The objects must be regarded as wrought products, fabricated from a rod, or perhaps pieces of sheet copper, and they are quite normal examples of small copper smithing, well within the capacity of any Egyptian copper smith. The formation of the eyes or loops was quite a delicate operation, and the only one calling for any degree of skill, some small tools must have been available for this part of the work. The substantial absence of corrosion in objects of such age is interesting, and indicates that the environment within the tomb was very favourable for the conservation of copper.

REFERENCES

1. Howard Carter The Tomb of Tut-ankh-Amun. Vol III. (1933), pp 89-93, Pl XXVII.
2. Alfred Lucas. Ancient Egyptian Materials and Industries. (4th edition 1962), pp 196–7.
3. Helen Murrey and Mary Nuttall. A Handlist to Howard Carter's catalogue of objects in Tut'ankhamn's tomb (1963), p 12, No 316 a-p (subnumbers following that of Carter's plate XXVII).

ACKNOWLEDGEMENTS

Sincere thanks are due to the British Non-Ferrous Metals Research Association for providing analyses of the metal. To Dr George Parker for his interest and help, and to H J Case, Keeper, Department of Antiquities, Ashmolean Museum, and Joan Payne, for the references given to the literature.

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After a distinguished career as a railway mechanical engineer, H H Coghlan became honorary curator of the Newbury and District Museum, founded and made famous by Harold Peake the collaborator of the anthropologist and geographer, Professor Fleure. H H Coghlan has contributed many papers on the properties of early metal objects and other aspects of archaeometallurgy. He was chairman of the Ancient Mining and Metallurgy Committee of the Royal Anthropological Institute, a committee that will be remembered for a lot of sterling work in the early days of our subject. He has written two authoritative monographs for the Pitt Rivers Museum, Oxford: Notes on the prehistoric metallurgy of copper and bronze in the Old World, and Notes on prehistoric and early iron in the Old World.

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Dr Varoufakis is head of the Research Department of the Halyvourgiki Steelworks at Eleusis near Athens in Greece. He has for a long time taken a keen interest in the metallurgical problems raised by early metallurgical artifacts in Greece. He has worked on corrosion problems on the bronze statues of Apollo and Artemis excavated in the Pireaus in 1959.

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Ronald Tylecote, chairman, editor and founder member of the Historical Metallurgy Society, has been with the Department of Metallurgy at the University of Newcastle-upon-Tyne since 1953.

Following a Trinity Hall, Cambridge MA with an MSc at the University of Manchester, he became an ICI Fellow at the University of London, where he took his PhD.

In 1939 he joined Professor H Fleure in an archaeometallurgical excavation and after a period of training in archaeological techniques, has taken part in Roman, medieval and post-medieval excavations, specialising in metallurgical problems while often also directing the excavations.

Since 1960 he has visited sites in Nigeria, Israel, Iran, Afghanistan and Turkey, in an advisory capacity, in conjunction with the Universities of Tel-Aviv and Khartum, the Pitt Rivers Museum at Oxford and the Smithsonian Institution.

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Erik Tholander

Dr Tholander is now a metallurgical consultant; he will be remembered by many as a regular contributor to the journal 'Metal Treatment and Drop Forging' where he has published articles on the effect of residuals on embrittlement in drop-forged steels. More recently he has been working with the historical section of the Swedish iron and steel institution, Jernkontorets, on archaeo-metallurgical problems connected with iron and steel.

Comments on medieval Swedish Osmond iron

by Erik Tholander

Osmund iron was an essential export article in Swedish trade during the Middle Ages. Two of its properties are well known and documented:

1. The ductility and forgeability had a very good reputation.
2. The weight of the piece was regulated to a fixed minimum (near 0.3 kg).

Other details and its production technology are little or not at all known and therefore subject to speculation. But the Osmund process being a direct reduction process is a very old tradition.

Some authors have a wrong definition of the word 'osmund' as applied to the bloom of a direct process furnace. 'Osmund iron' is originally applied to iron in pieces, forged and cut into a certain minimum weight. It was sold in 'hundreds' (120 pcs), 'barrels' (480 pcs) or 'läster' (12 barrels). 'Osmund' for the bloom is more recent.

In the 16th century Gustaf the First made great efforts to control the production of Osmund iron and pig iron and to get it refined and forged to bar iron by using waterdriven hammers. In 1604, the Swedish Parliament drastically reduced the osmund iron export; in the 1630's the export was prohibited and in 1641 the formerly compulsory tax registration of the yearly production was withdrawn. Some production then was still allowed, but the quantities and the time when it definitely ceased are unknown.

The technology of Osmund iron production is still not quite clear. In the literature no certain contemporary description is known, even if there are a few indications which are, unfortunately, interpretable in different ways. Almost all detailed descriptions of the Osmund iron process are from the 18th century, beginning with P Saxholm (1725) and Emanuel Swedenborg (1734). Later on Sven Rinman (1782 and 1788/-89), R Åkerman (1863) and E Odelstierna (1916) have made contributions. In English, John Percy (1864) in his Metallurgy – Iron and Steel, summarized the knowledge available in Swedish sources. Modern papers on the subject are written by Alf Grabe (1922), Knut Winge (1941) and Erik Tholander (1973).

The difficulties in the correct understanding of the real Osmund iron technology are due to the use in the old sources of terms having no certain definition (eg. 'masugn', 'smälta' etc) as well as the fact that even most of the early authors had no personal experience on the subject and were therefore depending on older oral and written sources beyond effective confirmation.

The source of Osmund iron best known outside Sweden might be the 'De Ferro' by Emanuel Swedenborg, written in Latin and printed 1734 in Dresden. Percy refers to it and therefore it could be of some interest to look at some details there regarding the raw materials, the furnace and its operation and, of course, the product.

Raw materials

Swedenborg devoted a separate chapter, No 5, to the Osmund iron and its production. He starts with the statement that the first type of ore was the bog-ore which only slowly – 'in the course of time' – was changed to rock ore. Unfortunately, this description cannot be correct for the "real Osmund iron period", which lasted from the (early ?) 13th century to the late 16th century. This can be said because in 1340 and 1354 King Magnus Erikson issued two well known privilege letters to groups of iron works owners ('bergslag'). In these it is quite clear that already at that time only rock ore was used in those districts and that the furnaces were driven by water driven bellows. That does not exclude an earlier stage using bog-ore and muscle-driven bellows but that seems not to belong to the main Osmund iron period. Such domestic iron-production with prehistoric techniques used by peasants in a small scale survived in isolated bog-ore districts into the 19th century and has sometime wrongly been described as 'Osmund-iron' production.

In all cases charcoal has been the main fuel.

Furnaces and their operation

John Percy (p. 321) has two figures on 'Osmund furnaces' extracted from Swedenborg's 'De Ferro'. These figures, however, belonged to Swedenborg's Chapter 3 dealing with bog-ore, and the iron made domestically from that (the 'myrjärn'). But the fact that Swedenborg started his description of the old Osmund iron production in Chapter 5 by saying the ore was bog-ore, made it quite natural to his readers to take the figures shown in Chapter 3 as relevant also to Chapter 5. In reality, however, the Chapter 3 figures (Tables VIII, IX, X) do not originate from P Saxholm, Swedenborg's source on Osmund iron, but from L Schulze (1732), his source on 'myrjärn' (bog-ore-iron).

In this way has arisen the discrepancy between the figures of Chapter 3 and the description in Chapter 5 of an 'Osmund furnace'. The text reads:

".....The construction of the smelting hearth itself was such, that in the back wall through a smaller opening located close to the ground, entrance was obtained to the interior, and this opening (had) bellows positioned which were moved by human power. Because in the old days the use of waterpower was unknown. In the front wall there was a larger opening, which however, as long as the smelting lasted, was strictly closed by well fitting stones, until the bog-ore was completely smelted then the stones were taken away and the lump was extracted in the condition it had."

After that the bloom is said to have been smelted a second time in the same furnace in order to obtain a better and cleaner iron.

The discrepancy concerns the "smaller opening close to the ground" and the tuyere of the figure located one foot above hearth bottom. The difference, less than 12 inches, might look small. From other parts of 'De Ferro' dealing with furnaces, it is quite clear that a distance of one foot above could not be described as 'close to' the ground,because shorter measures such as 4 and 6 'fingers' are given in the figures. The conclusion must be that there had been furnaces of different construction in the old Swedish iron works.

Now it seems to be of some interest that the present author excavated a furnace in 1972 in south Dalarna – at Harhyttan – having a long, low opening (about 100 x 20 cm) in the 'backwall' close to the hearth bottom and opposite to a large opening in the 'frontwall' closed temporarily by stones bonded with clay. This low opening had served as an air supply channel. The design was formerly unknown – as far as I know – but it fits in exactly with Swedenborg's description. This cannot be applied to the ordinary type of small bloomery known from the 18th and 19th centuries because of the openings.

After his description of the "old Osmund process", Swedenborg gave a view of "the newer way of smelting Osmund iron". Here he mentions "richer ore deposits", alluding to rock ores, and "small hearths similar to the bloomeries already mentioned and built close by small rivers and streams". The iron from these new hearths was said not to be worked in the same furnace but in the hearth of the forge. The further description makes it clear that here it is pig iron production and its fining that is being done.

Thus, Swedenborg as well as other authors from the late 17th century and into modern times shows that there was a conversion of an old direct reduction Osmund process into a newer indirect process using cast iron. Neither he nor anyone else gave any chronological landmark for that conversion and this may be the reason for a lot of confusion about the nature of the Osmund iron and its technology. The information on ores and furnaces did not make the picture very clear.

The "Osmundgruppen" and later research

In 1922, Alf Grabe summarized the knowledge of that time very carefully in a paper printed in the Jernkontorets Annaler, and in 1941 Knut Winge wrote another big summary – more speculative. During the 1960's a new interest grew in the history of technology and ironmaking in Sweden, and in 1970 a research group of scientific and technical specialists was formed under the name of "Osmundgruppen". Beside some linguistic and historical studies most of the work of the group was devoted to microscopical examination of a great number of old iron artefacts and slag finds as well as critical analyses of different technical aspects. Also, an excavation was made – as already mentioned above – on an old furnace, which revealed design details belonging to the Stückofen type of furnace, whose existence in Sweden was unknown according to official sources but which had been surmised by the present author in the Osmundgruppen. The work of the Osmundgruppen was discontinued in 1973 without reaching a total solution of the Osmund iron problem. A report leaving the most essential questions open was published by Jernkontoret in July 1973. In addition the present author at the end of 1973 published a paper on his own research within the Osmundgruppen after the joint work had ceased.

'Osmund iron' and a summary of its technology

The conclusions that it is now possible to draw can be summarized briefly:

The first proof of Osmund iron as an export article has been shown to originate from about 1280 (not 1252) as has been claimed earlier). The word 'osmundsjärn' could for certain linguistic reasons, be interpreted as "the iron from the furnace's mouth".

Concordant linguistic, historic-technical, metallographic and archaeological indications point to the Stückofen-type of furnace as the most significant phenomenon of the medieval Osmund iron period in Sweden apart from the fixed Osmund pieceweight. The initial event is assumed to have been the treaty (1170–80) in Lubeck between Henric the Lion and Knut Erikson of Sweden which opened the Swedish trade ports to the German Hansa-organisation.

The Stückofen-furnace, using waterdriven bellows, was a new invention in the Alpine-countries in the 12th century, and Henric the Lion had documented the connections with that region. German settlements are known in Swedish ports from the late 12th century and in some iron-producing districts of central Sweden in the 13th century. According to archaeological statements, the number of waterdriven iron works expanded widely during the same period. In 1340 the use of rock ore and water power for making iron was the normal technique. No other type of furnace, known at that time, was more suitable for the reduction of rock ore than the Stückofen. It has not been proved that the blast-furnace existed earlier than the 16th century – the time when the fining of pig iron to wrought iron is first known. An exception seems to be the Swedish 'loppejärn', first mentioned about 1460 and possibly made of cast iron from Stückofen-furnaces.

Slag inclusions in medieval iron-pieces indicate reduction furnaces producing both wrought and cast iron; and, finally, the furnace excavated at Harhyttan was clearly built as a Stückofen-furnace.

There is still a need for further investigation, especially metallographic examination and excavation of more furnace-remains, of which a lot of respectable age are still left in many places in Swedish Bergslag-districts. But our picture today of Osmund iron is clearer and less confusing than it was up to 1973.

LITERATURE

Grabe, Alf: Jernkontorets Annaler 1922, Tekn. disk. möte p 5 – 61.

Jernkontorets Forskning, Serie H, No. 8, 10.7.1973.

Odelstierna, E.: Järnets Metallurgi, Stockholm 1916.

Percy, John: Metallurgy, Iron and Steel, Section II, London, 1864.

Rinman, Sven: a) Järnets Historia, Stockhom, 1782

b) Bergwerks Lexicon, Stockholm, 1788, 1789.

Saxholm, Per: Dissertation on Swedish Osmund Iron, Upsala 1725. Translated into Swedish by E B Hammarskjöld 1916.

Schulze, Lars: Report on 'Bläster-Werk' to Bergs Collegium 1732. Printed in Jernkontorets Annaler 1845 "Om Osmundsjärn".

Swedenborg, E.: Opera Philosophica et Mineralia, II, De Ferro, 1734. Swedish translation by Hj Sjogren, 1923.

Tholander, E.: Osmundsjärnet i ny belysning, Bergsmannen No 9/10, Stockholm 1973.

Winge, Knut: Om osmundsjärn, Jernkontorets Annaler 1941.

Akerman, R.: Jernet, Stockholm 1863.

Spring mini-conference

As an experiment, the Council of the Society arranged for the 1975 AGM to take the form of a residential weekend conference. It was based on the Caer Llan Field Centre, near Monmouth, in beautiful surroundings, attracted a record attendance, and was a great success — not only because of the excellent programme, arranged by Amina Chatwin and Ian Standing, but also because of the good weather and the superb food provided by the Warden, Peter Carpenter, and his staff. Apart from the short business meeting, the indoor proceedings comprised talks by Ian Standing, Stan Coates, and Gordon Tucker in preparation for the field trips they were to lead, together with talks by Torsten Berg on the observations of the Swedish traveller Angerstein, by David Bick on the remains of a furnace at Newent, by Amina Chatwin on the furnace at Gunn's Mill which was later disguised as a paper mill, and by Alan Batty on the replica of Locomotion No 1.

The field trip on Saturday afternoon was led by Ian Standing, with Stan Coates taking over for the Dark Hill site, which was the scene of much of David Mushet's activity. It was therefore appropriate that we should call at Staunton Church to see Mushet's grave, and later have tea at Forest House which was his home from 1810 to 1843 and then his son Robert's. Ian took us past many interesting places in the Forest of Dean on the way to Blackpool Bridge, where we inspected the remains of the controversial "Roman road" and the puzzling "Drummer Boy" stone which shows unmistakable signs of association with iron working. Then to Dark Hill, where Stan showed us over the remains of the ironworks including a small blast furnace — an important enterprise in the first half of the 19th century — and then on to the very fragmentary remains of Mushet's experimental steelworks, which as the "Titanic Steel and Iron Co." produced "R. Mushet's Special Steel" from 1868 to 1871. After tea we visited Whitecliff furnace, a reasonably well-preserved coke blast furnace of 1802, fortunately now being taken care of by sympathetic new owners.

On Sunday morning there was a choice of outings, the hardy minority going underground in an old iron mine with Ian Standing and some of his friends, and the rest following Gordon Tucker on a tour of the remains of the old wireworks and ironworks at Tintern and Whitebrook, which have been the subject of recent articles in this Journal.

Thanks are due to all concerned for an excellent weekend.

DGT

Gold is where you find it

The following, which appeared in "The Lizard", vol. V (2), 1974, p. 26–27, was communicated to us by Roger Penhallurick of the Cornish County Museum at Truro and is reproduced by courtesy of the Editor of "The Lizard".

Great excitement ran through The Lizard village last November when two schoolboys, Nicholas Casley, 15, and Steven Richards, 14, both of Parc-an-Ithan, found several gold ingots in the soil of the cliff top, 125 ft above Pentreath Beach.

Chasing a rabbit along the cliff path, Nicholas kicked a stone and heard a metallic sound. Where the stone had been, lay a small piece of yellowish metal, 1½ inches long, 3/8 inch in diameter. Searching around, the boys found seven more pieces, and next day another eight. These were all of similar shape, triangular in cross-section and tapering to a point at each end. The upper surface of each casting was convex and the other two sides were concave, the metal showing dendritic crystallisation.

Technical evidence was given by Mr Wootton at an inquest on 5th March, 1974, held at Helston by Mr Geoffrey Robins, who said that in almost 40 years as Coroner and Deputy Coroner for West Cornwall, this was his first treasure-trove inquest.

"An inquisition taken for our Sovereign Lady the Queen at the Guildhall, Helston, on the 5th day of March, 1974, before Geoffrey Lionel Robins, Coroner for the said County of Cornwall, upon the oath of" eight good and lawful men "of the County of Cornwall, duly sworn and charged to inquire . . . concerning certain treasures found and now here produced, when, where, how and by what means, and by whom the said treasure was found and having heard evidence upon oath, do further upon their oaths say that the said treasure consisting of sixteen gold bars . . . was found . . in the soil of the cliff at Pentreath Cove, the Lizard in the said County of Cornwall, by Steven Peter Richards and Nicholas Casley, and the jurors further say that the said treasure was of ancient times abandoned or lost."

"This is not treasure trove and the gold belongs to you," the Coroner told the boys to their great delight.

The total weight of the bars is 361.9 grammes (approximately 11½ oz Troy). At current value, the intrinsic value of the gold metal would be £500–£600. This excludes any value which might accrue by reason of the antiquity of the bars.

A full analysis was carried out on three of the bars and, in addition to the gold content, the figures obtained are as follows:

Palladium 0.0003–0.0005%, Antimony 0.002–0.003%, Arsenic 0.002%, Bismuth 0.01%, Chromium 0.0001%, Copper 12–17%, Tin 0.2–3%, Iron 0.01%, Lead 0.1%, Manganese 0.0003%, Nickel 0.005–0.007%, Silicon 0.005–0.008%, Silver 4–7%, Zinc 0.0005–0.002%.

The gold bars were examined by Mr R W Wootton, Senior Scientific Officer (Metallurgist) at the South-West Forensic Science Laboratory, Bristol. Spectrographic analysis of the bars indicated that they were all made from gold containing substantial proportions of copper and silver, and lesser quantities of tin, lead and bismuth. The specific gravity of each bar was determined and found to be within the range 15.0–15.5. This corresponds approximately to 18 carat gold (i.e. 75% by weight gold). Gold assays were carried out on three of the bars and these confirmed the proportion of gold as 73–77%.

On the basis of these figures, it can be deduced with a fair degree of confidence that this gold is at least several hundred years old. Gold from most modern sources, notably South Africa, has a detectable quantity of tellurium, which is absent from these bars. The relatively high levels of tin, lead and bismuth present suggest a much lower standard of refinement than has prevailed for many years. Naturally occurring gold may contain any proportion of silver, up to 5% copper and up to 0.2% tin. It may, therefore, be deduced that the copper and tin in these bars have been added subsequently, either intentionally or accidentally. The high level of copper excludes accidental addition, however. The practice of adding copper to gold, either as debasement or to harden it, is reckoned to have started around 2,000 years ago. The proportion of tin present, in conjunction with the copper, suggests that the gold was alloyed with copper containing tin.

It may also be significant that the specific gravity of the bars corresponds to that of gold coins of a type known as Gallo-Belgic 'A' which were regularly imported into this country from Gaul about 2,000 years ago.

Some significance may be attached to the weights of the bars, and their combined weight. Of the 16 bars, nine lie within the range 22.0–22.3 grams, which is a very accurate range. Four more lie within 1.5 grams of this range. The remaining three bars are 11.6, 27.1 and 29.2 grams. The fact that so many of the bars are so similar in weight suggests that they were deliberately cast to be that weight. The mean weight of the nine closely grouped bars is exactly one-sixteenth part of a Celtic pound thought to have been in use in the Mendips for silver. The combined weight – 361.9 grams is also close to one of these Celtic pounds – 353 grams. The mean weight of the nine bars is also exactly three times the weight of a Gallo-Belgic 'A' coin.

CONCLUSIONS

The bars may, with confidence, be dated as being 200–2,000 years old. A more exact dating is difficult, but on the basis of the weight of the bars, it seems likely that the bars are associated with the earlier end of this period, possibly 1,500–2,000 years old.

ACKNOWLEDGMENTS

We are grateful to Mr R W Wootton of the South-Western Forensic Science Laboratory, Bristol, for permission to publish the results of his examination of the gold bars. We would express our thanks to the Coroner, Mr G L Robins, on whose behalf the work at Bristol was carried out. The friendly help of Mr L Richards of Parc-an-Ithan is also acknowledged. WARNING – We would point out that these cliffs are dangerous. There have been three cliff falls in about 30 years, as the cliff has been greatly weakened by faulting, and fissures are still present.

Book review

EIGHTEENTH CENTURY GUNFOUNDING. THE VERBRUGGENS AT THE ROYAL BRASS FOUNDRY, A CHAPTER IN THE HISTORY OF TECHNOLOGY
Melvin H Jackson and Carel de Beer, 245 x 190 mm, 183 pp, 1973, Newton Abbot, David and Charles, £5.25

In 1716, after the startling discovery that the royal stores of brass ordnance for the United Kingdom contained but two 12-pounders and not a single 18- or 24-pounder, it was decided to build the Royal Brass Foundry, on Woolwich Warren, close to the Royal Dockyard. The architect of the buildings, which exist to this day, was Sir John Vanbrugh, the first manager Andrew Schalch from Douai, a notable foundry town of Flanders. For some fifty years Schalch managed, and progressively mismanaged as he failed to keep up with modern techniques, the Royal Brass Foundry, and by 1770 the Foundry was in a sad state and the Kingdom as badly off for arms as ever.

At this point, the Ordnance Board thought themselves lucky to obtain the services of Jan Verbruggen, master founder of the Heavy Ordnance Factory at The Hague, together with those of his son Pieter, for the same price as the elderly Schalch – to be quietly pensioned off – had been receiving since 1717. The Verbruggens were at that time rather under a cloud in the Netherlands; Jan was accused, and rightly as drawings in contemporary reports show, of filling up faults in his gun-castings with screwed plugs, tenoned patches, and so on. He was above using the mixture of oxblood and metal filings that other founders employed for the purpose. His own view was that these were cosmetic repairs, and that the flawless barrels that the authorities required of him were unattainable and unnecessary. His guns did, in fact, pass proof, but he had enemies; rather than accept a compromise which would have removed him from technical control, he entered the service of the Ordnance Board with his son and all his household, and began some 16 years of innovation and solid service. At no time does it appear that there were complaints of defects and their treatment; at Woolwich, Verbruggen was able to start from scratch and control every aspect of manufacture. The proportion of his guns failing to pass proof was 2.6%, while in the case of Schalch it had been 27.2%, and two contemporary outside contractors had only achieved failure rates of 13.3 and 16.1%.

His real innovations were two: the boring of cannon on a horizontal machine tool which rotated the gun whereas earlier machines had suspended the gun vertically over a rotating tool, and the casting of solid, and not cored, barrels. The horizontal boring mill was not an original invention of Verbruggen's, but he had much improved upon the design of the originator, Johann Maritz of Burgdorf in Switzerland. John Wilkinson also knew of this design and patented his own version in 1774, after Verbruggen's report on a number of defective iron cannon from The Carron Company had led to the decision that all cannon should be cast solid and bored out.

Verbruggen's opinion was clearly worth having. He understood ironfounding as well as he understood other types of of brassfounding; in his time he had cast church bells and pharmaceutical mortars. It was his work in brass ordnance at the Royal Brass Foundry which was to continue, however.

Very necessary it proved to be; the American colonies were simmering in revolt, and some seventy light cannon were soon required and rapidly produced, in time for some to be surrendered by Burgoyne at Saratoga in 1777 and others by Cornwallis at Yorktown in 1781. Examples of these are among the few Verbruggen cannon to survive; brass and bronze had, then as now, a very high scrap value.

The authors of this book, Melvin H Jackson of the Museum of History and Technology in Washington, and Carel de Beer, a Dutch historian who is unaccountably called Charles on the dustcover and the spine of the book, relate all these events and more in a clear and lucid style as much at home with historical events as with technology. The work could stand alone as a small masterpiece even without the illustrations which it was written to explain, but these make it a unique contribution to the history of technology. There are no less than 50 pencil and wash drawings, by either Jan himself or his son Pieter, dealing with every aspect of all the processes of solid gunfounding; model-making, where a full-size pattern was built up on a spindle, the covering of this with loam to make a mould, the fire-drying of the mould and the removal of the pattern, the addition of the trunnion and cascabel moulds, the embedding of the completed set of moulds in the casting pit, the melting of the charge – often including condemned and captured cannon – the pouring operations, often for several cannon at a time, and finally the boring, with simultaneous turning of the outside, on the machines of Verbruggen's design and construction.

These drawings are attractive in themselves and are of almost photographic accuracy – only a Verbruggen could have done them – and they are accompanied by the authors' own explanations in considerable and very clear detail. Nowhere else can be found such a view of 18th century product engineering, not even in *La Grande Encyclopédie;* we are fortunate that these drawings were preserved in the de Vries van Doesburgh family, and that there are authors who have the skill and knowledge to explain them to us. Of Verbruggen's work, 26 cannon, eight bells, two pharmaceutical mortars, and these drawings, remain; there is no doubt which are of the greatest value.

J P Saville

This review originally appeared in 'Metals Technology', September 1974, and is reproduced by courtesy of The Metals Society.

Letters to the Editor

From K C Barraclough

Sir

Steel in Scotland

In your review in the Journal, 1974, Part 2, page 102, it is implied that the Hallside plant produced the first structural steel in Scotland. While this may be so, it is important to place on record that the Cramond works on the Forth, sold to the Cadells in 1769 or thereabouts, produced steel by cementation until into the 19th century (see Sinclair's Old Statistical History); in addition, the Albion Works at Linlithgow under Hawksworth were producing steel by the 'Sheffield' methods at the time of the 1867 Exhibition (See Samson Jordan's report). Furthermore, it appears quite clear to me that Siemens was proposing his own pre-reduction steel making process to deal with the Blue Billy, as per his Patent No 1892 (AD 1868) but suggested the Siemens Martin process for ordinary steelmaking on the site. The minutes of the meeting which are reproduced in the booklet quite clearly indicate that Siemens granted licenses for both processes; the Blue Billy experiments proved to be a failure, as had the earlier trials in the Midlands, although it is clear that the principles were correct, as evidenced by the current use of rotary kilns for the production of pre-reduced iron ore.

Yours faithfully,

K C Barraclough 11th April, 1975.

From Professor Ursula Franklin

Dear Sir

By now you will probably have received many letters pointing out the silly irony that B G Scott's "Notes on the development of the metallographic studies of ancient iron" published in Nr 2 of Vol 8 of "Historical Metallurgy" follows a paper by C S Smith; and Scott makes no reference to Cyril Smith's contribution to the metallographic study of ancient iron. Frankly, it is quite beyond me that anyone could work in this field without knowing Smith's "History of Metallography", "The Techniques of the Luristan Smith", "The Discovery of Carbon in Steel", his comments on Sorby or Réaumur, to mention only a few.

Yours faithfully

Ursula Franklin
Professor of Metallurgy and Materials Science
University of Toronto 26 May 1975.

Reply from B G Scott

Dear Sir

There appears to be a certain amount of misunderstanding of the theme and purpose of my short note in the Journal 8(2), 1974, 88–91. The sole aim was to try and indicate the development of what appears to me as the important dichotomy between research approaches which study ancient ironwork purely from the metallographic/chemical standpoint, and those which collect the 'scientific' data, but then go on to use it in the construction of an overall picture of the ironworkers and the societies in which they operated.

Since the last thing I was attempting was a palaeometallographic 'Who's Who' or Bibliography, I am well aware of the ommissions of names and works from the list of references. Certainly in a paper of much wider scope, one would naturally pay much more detailed attention to the research being carried out in Prague, notably by Radomir Pleiner; to the work of C.S. Smith, particularly in regard to his work on early texts; to the contributions of the Hon. Editor of this journal; to the publications of Anteins, Cleere, Coghlan, and many others. If inclusions or ommissions seem illogical (or even unfair) to some readers, I can only point out that the title of my paper was 'Notes on. . .' and not 'A Definitive History of . . .'. I would also re-emphasise that it was written specifically to highlight one aspect of methodology.

I am now able to give full references to the works of Victor Tahon mentioned in my text, thanks to the kindness of Mr L P Verbois, Ing. Techn., AMP, of Liège, and also to give Tahon his proper nationality Belgian, and not French. The three papers mentioned in note 1 of my paper were all published in

Documents et Rapports de la Societe d'Archeologie et de Paleontologie du canton de Charleroi (DRSAC).

and the references are (in the order in which they were listed)

DRSAC, XIV, 1888, 227–246;

DRSAC, XIV, 1886, 763 – 806 (Published in Mons);

DRSAC, XVIII, 1891, 215–240.

Yours faithfully

B G Scott
Conservation Laboratory
13 University Square
Belfast

from Kenneth C Barraclough

Dear Sir,

In my survey of the production of steel in Britain by the cementation process which appeared in the last issue of the Journal (JHMS, 1975, 9(1)), I stated on page 105, "We know that iron was puddled in Sheffield, presumably using mainly home-produced pig iron, from 1858 onwards". It has, however, recently come to light that there was a significant occurrence in Sweden, which leads me to feel that this statement needs correction.

It had long been official policy in Sweden to prohibit the export of Swedish cast iron and only to send out the bar iron produced from it. On December 19th, 1855, however, this policy was changed. Within two or three years, two results of this action could be observed in Sheffield steelmaking premises: in the first place some mixtures of Swedish bar iron and white cast iron were being melted together in crucibles instead of blister steel and, in the second place, there were puddling furnaces at the premises run by John Brown, Charles Cammell and Thomas Firth. Imports of Swedish cast iron via Hull in 1862 amounted to almost 8000 tons (the total British import being 11000 tons during the year). As it sold at between £6 and £7 per ton as gainst around £3.10.0 per ton for home produced material, it clearly was used for special purposes. Furthermore Samson Jordan, reporting on Sheffield steelmaking in his report on the Paris Exhibition of 1867, makes specific comment on the import of Swedish cast iron in connection with the production of puddled steel by John Brown and Co.

It seems clear, therefore, that I should modify my comment on the type of iron used for puddling by the Sheffield steelmakers; the rise of this process there may well have derived from the Swedish action.

Yours faithfully

K C Barraclough

1975 Autumn conference at Dumfries

19/21 SEPTEMBER 1975

About 50 members and their guests attended the meeting, staying in a variety of hotels and guest-houses centred on the Lorburn Halls, where the meetings for lectures and discussion were held.

Proceedings began at 7 pm. on Friday evening with a brief address of welcome by Mr. A. E. Truckell, President of the Dumfriesshire and Galloway Natural History and Antiquarian Society, Museum Curator for the Nithsdale district and a distinguished historian and archaeologist. Dr Swinbank then introduced the Wanlockhead district, with topographical and geological maps and photographs, setting the background for the Saturday morning visit. He was followed by Dr Tylecote, who described typical lead smelting furnaces and the processes which go on within them. Mr David Smith then spoke on the history and business of the Dalmellington Iron Co. drawing attention to its geographical spread and the way in which it was bound together by a private railway system. Mr Smith concluded with slides of the plant in its iron smelting days and of some of the splendid steam locomotives employed. These talks were followed by shorter contributions from

Richard Doncaster	'William Coutts or Cotts : Fact and Fiction"
Norman Swindells, Jnr.	"Mote of Mark finds"
Lynn Willies	"Latest on Lead"

The meeting broke up at 10 pm. feeling prepared for the following day, but emerging into a threateningly wet and stormy night.

The party re-assembled next morning in the station yard and (to the relief of at least some) in fine weather. Departure was on the stroke of 9 am. The route followed was up Nithsdale to Carron Bridge, then over the Dalveen Pass to Elvanfoot – passing through some of the finest scenery in southern Scotland. From Elvanfoot the route of the old railway (c.1900–1938) was followed to

Leadhills, with a pause at Risping Cleuch to admire the handsome brick and concrete viaduct. Perhaps the difficulty experienced in persuading the party to re-board the coaches was connected with the phrase 'old gold workings' found on the maps just here. The next stop was at the car park in Leadhills, at which point Dr Swinbank pontificated on the local workings and worthies. Some of the more macabre-minded members insisted on visiting the cemetery. From here the party drove slowly to Wanlockhead, with some of the more notable features being pointed out en route. At Wanlockhead the first stop involved a short climb to the point at which the mineral tramways joined the standard-gauge line, a bleak and wind-swept spot which, nevertheless, provides a slendid viewpoint of the workings in the upper part of the Wanlockhead Valley. Then, along the narrow road to the Meadowfoot smelter, where was the longest stay of the day. Astonishment was expressed at the system of wooden flues, and there was a good deal of speculation about the operation of the smelter. The condition is now so ruinous that accurate mental reconstruction is almost impossible, and there are features whose function is hard to fathom. From this point the coaches returned to a suitable parking spot, and lunch was taken by some in the coaches and by some at the ruins of the Bay, or Charles, Mine in Whyte's Cleuch which is the scene of much activity by the University of Glasgow Summer Schools in industrial archaeology. There was then time to walk gently through the village, admiring the famous beam engine and noticing lades and tramways before catching the coaches to be transported rapidly down the Mennock Pass to Sanquhar and the Nithsdale Arms, which was reached only 5 minutes late and well before closing time.

After refreshment the ride was continued to Dalmellington, where Mr Smith pointed out the position of the blast furnaces, long since demolished, the still-existing massive retaining wall, which was one of the first structures to be built on the site, and the handsome blowing engine house of 1847. Though it is now many years since the furnaces were closed at Dalmellington the site is still very well worth visiting, since the topographical details can still clearly be seen and the way in which the iron ore and coal workings were brought together can be followed. To conclude the visit Mr Smith was able to show two of the locomotives, one of which, number 17, was bought in 1913 and is still in steam, but the high spot for a few members of the party was the discovery of the nest of a barn-owl. From Dalmellington the return journey to Dumfries was made by the New Galloway-Castle Douglas road, passing alongside picturesque lochs in more splendid countryside. The party arrived back in Dumfries at about 5.30, and was faced with the problem (which proved insoluble for some) of getting a meal before the meeting resumed at 7 pm.

Saturday evening, 20 September 1975

Andrew Oddy	**"Hand made gold wire in prehistoric times"**
Janet Lang	**"A silver dish"**
Paul Craddock	**"Reflections on classical mirrors"**

Saturday evening began with a group of 3 excellent short "work in progress" reports by members of staff of the Research Laboratory of the British Museum, who have been investigating various aspects of the early production of ornamental metalware. These 3 papers demonstrated very clearly how the techniques and knowledge of the metallurgist have an impact on the work of the archaeologist and art historian. Later in the evening, after a most entertaining talk from John Butler on Martin's shells (which were to be filled with molten iron before being fired at the enemy), Ken Barraclough and Dr Peter Swinbank spoke briefly of the early blast furnaces at Furnace, Bonawe and Glen Kinglass, Furnace and Bonawe being those visited by some of the party later on.

If some of the party had difficulty in getting dinner on Saturday night, others had difficulty in getting breakfast on Sunday morning before assembling at the Burgh museum at 9 am. Mr Truckell showed the party his magnificent and wide-ranging collections, with appropriate emphasis on metal working. This visit was vastly enjoyable and instructive, with show-cases being opened so that objects could be handled. After coffee the meeting resumed in Lorburn Hall with an address by Mr. Truckell on the metalliferous archaeology of S.W.Scotland. This talk was illustrated with slides, and was an excellent summing-up of much of the earlier part of the meeting and of the visit to the Museum. The final paper was an account by Mr. James Williams of the mineral and metal working of the whole of S.W.Scotland, with particular emphasis on activities away from Wanlockhead. Thus, the Sunday morning session provided a larger perspective, bringing out how varied metal working activities have been in this district from early times. The meeting concluded at about 1 pm.

One comment which was heard was that Mr Truckell and Dr Swinbank had each provided examples of perpetual motion.

Then some 19 intrepid conferees set off northwards to see the blast furnaces at Bonawe and Loch Fyne. We all met together in the Lochearnhead bar of the hotel at Lochearnhead to plan our visit. The next day, as occasionally happens in Scotland, proved wet and we had a very wet look at the newly restored Lorn furnace at Bonawe. The Scottish Department responsible for the restoration had done a magnificent job which was nearly finished. We tramped across delightfully mown lawns. We saw the ore sheds, charcoal sheds, and the furnace itself with its bridgehouse. The lintel beams had been nicely painted with their date of 1753 well in evidence. The wheel pit looks as though there is still work to do upon it.

In complete contrast to this expensive but highly successful piece of restoration was the furnace at Furnace on the shore of Loch Fyne. This was much as it was when last seen in 1956 except for a bit more dumping of rubbish behind and a few more trees in the stack. But it did stop raining! This furnace must be unique among British blast furnaces in that the tuyere is still in position amidst the 'bear' in the bottom of the furnace. This will give us very valuable information when its turn for restoration comes.

This completed the week-end, and the British amongst the 19 prepared to return home while the 6 North Americans went on to see more of Scotland.

The Editor acknowledges the help he is receiving with the abstracts. We are 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 and A P Woolrich.

Abstracts

GENERAL

Theodore A Wertime. The beginnings of metallurgy; a new look. *Science 1973,* **182** *(4115), 875–887.*

The close inter-relation between different types of pyrotechnology, i.e. use of fire to fabricate plasters, ceramics, metals, glazes and glass, is stressed. Modern trends in studying early metallurgy are summarized: metallography, chemical and spectrographic analysis; trace element analysis, archeometry; isotopic analysis; geophysics, geochemistry and economic geology. The history of the rise in Western Asia of the metallurgy of the major metals and their impurities is summarized: copper (including native copper, casting and smelting, and origins of bronze): lead and silver; tin, iron. The article includes maps, and a table of earliest occurrences of metals in S.W. Asia. EWF

J P P Blanc: 100 years of decorated boxes made from tinplate. *Rivestimenti, 1972,* **1** *(10), 163–166. (In Italian).*

The history of printed tinplate biscuit tins and similar containers is traced from about 1840. Examples of historical and modern tinplate ware are illustrated. MG

Allan B Dove (Ed): Steel wire handbook, volume 3. *Book, Wire Association, Branford, Connecticut, 495pp. 1972, illustrated.*

Sixteen articles on modern steel wire applications are presented. Those on bridge wire, bridge strand and bridge rope (119–153), nail manufacture (317–330), barbed wire (331–352), and steel wire fence (353–378) give the historical development and some aid in classification of types. MG

J A Charles: Where is the tin? *Antiquity, 1975,* **49***,19–24.*

Discusses the problem of the apparent scarcity of tin and tin-containing minerals in the Bronze Age and suggests that trade in tin was often by way of cassiterite and possibly stannite ($SnS_2.Cu_2SFeS$) rather than as elemental tin. These minerals may have gone unnoticed by excavators. Details are given of their characterisitics as an aid to identification. The author favours the production of bronze by the direct introduction to copper of minerals of this type (i.e. by cementation) rather than elemental tin.

BRITISH ISLES

Richard Fifield: Bedlam (Coalbrookdale) comes alive again. *New Scientist and Science Journal, 1973,* **57** *(839), 722–724.*

An 'environmental museum' preserving and displaying iron-making plant and methods employed in the Coalbrookdale (Shropshire) area in the 18th century is described. Items discussed include the cast-iron bridge across the Severn gorge, the Bedlam and Darby furnaces representing the transition towards iron-smelting with coke, the Cranage technique for production of nail-rod, and the Cort puddling process. MG

J A Williams: Caring for "The Iron Bridge". *Construction Steelwork and Metals, Oct 1972, 14–17, 21.*

An examination of the first cast-iron bridge in the world, the Iron Bridge at Coalbrookdale, which was opened in 1781, is described. The inspection revealed that, on the whole, the cast-iron members were in good condition as far as corrosion was concerned, and that, despite considerable main abutment movement, fractures that had occurred were independent of this and probably could be attributed to secondary deflections of masonry. A remedial program is proposed which will include relief of the north abutment, reinforcing the strutting with concrete,and repairing the fractures in the cast-iron members. MG

J V S Megaw: Irish Middle Bronze Age spearhead in the Queensland Museum, Brisbane. *Mem. Queensland Museum 1973,* **16** *(3), 485–487.*

The author is with the University of Leicester. The analysis was Cu 85.8, Sn 12.3, Pb 0.002, Ag 0.02–0.05, Fe more than 0.2%, and a Vickers hardness of about 100.

B G Scott: Applications of metallographic examination of iron artefacts to Irish archaeology. *Ulster J Archaeol. ser. 3, 1971, 34, 87–95.*

The problems of studying iron artifacts are discussed and lines of approach suggested towards understanding the historical development of the iron industry from its first arrival in Ireland. BAA

Wendy Slemen: Liverpool's Cast-iron Churches. *Foundry Trade Journal, 1974,* **138** *(3039), 307–312).*

In 1812, Thomas Rickman, architect, collaborated with John Cragg, the principal partner in the Mersey Iron Foundry in Tithebarn Street, Liverpool, on the design of a church which was to feature extensive use of iron castings. Three churches incorporating their ideas were built in Liverpool, and one in Birmingham. Two of these buildings survive – St George's, Everton, consecrated in October 1814 and St Michael-in-the-Hamlet, Aigburth, consecrated in the following year. This well-illustrated article discusses the principal features of the buildings, and quotes extensively from Rickman's diaries in telling the story of the surviving buildings from the first conception of the idea to the present day.

EUROPE

Konstantinos Konofagos: The ancient Greek method of ore enrichment in lead ore washeries of Laurium.
Pragmateia, 1970, **29,** *(1), 3–17. 11 pls., 8 refs. (In Greek; Abstract in French).*

The lead ore washeries of Laurium, in use from the sixth to the second centuries BC, are described. Theories of the mode of operation are discussed. It is estimated that the yield of metal is slightly less than 63% (in the form of enriched ore containing 45% lead) based on experiments using a spiral washing, and that the capacity of a washery is four tons per twelve-hour workday.

Konstantinos Konofagos and Herman Mussche: The ancient Greek spiral ore washeries of Laurium: a forgotten invention of the ancient Greeks. *Pragmateia, 1970.* **29,** *(2), 3–21. 22 pls. 7 refs. (In Greek).*

A previously unknown type of lead ore washery, probably of the fourth to third centuries BC is described. A reconstruction in concrete of one of the washeries was made and its efficiency tested using a 60 kg sample of galena – containing ore (16% lead); 13.5 kg of enriched ore (45% lead) was obtained, corresponding to a metal yield of 63%. AHL

Jerzy Piaskowski: Was iron with a high content of nickel smelted in antiquity? *Zotchlani wiekow, 1971,* **37,** *(1) 24–26. (In Polish).*

It is commonly accepted that the oldest iron objects with a high content of nickel were produced from meteoritic iron. Was this the only source? The author (a prominent metallurgist) gives a negative answer. Thermo-dynamic considerations and laboratory experiments both show that nickel oxide is even more easily reduced to metal than iron oxides, so this could take place in primitive smelting conditions. Several finds in Poland (with high Ni content) were certainly made of smelted iron. The low content of silicon (sometimes also an argument for meteoritic iron) does not point to meteoritic origin, as meteorites do contain silicates. For identification of meteoritic iron Cr and Co should be considered instead. They may be in meteoritic iron in a few tenths of a percent, and only traces of them (if any) can be expected in primitively smelted iron. HJ

J Piaskowski: Metallographical investigation of two early medieval iron shares. *Silesia Antiqua, 1970.* **12,** *189–195. (In Polish).*

The plough-shares were found at Czeladz Wielka, distr. Gora. They were subjected to metallographical, physical (microhardness of components) and chemical (qualitative and quantitative) examinations. Before that, 22 items from the same site, dated from 6th–12th century, were investigated. The shares are made of iron with a high phosphorus content (0.27–0.54%) and with a slight primary carburization. The same was found for the other objects. This leads to conclusion that near the site there was a centre producing iron with high phosphorus content. A Ro

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Massimo Leone: The deterioration of metallic works of art by atmosphere corrosion. *Metallurgia Italiana, 1972. (6), 1–3. Illus. Bibliog. 24 citations.*

The chemical composition of six well known Italian bronze monuments are tabulated as follows:

	Cu %	Sn %	Pb %	Zn %
Grifo del Palazzo dei Piori di Perugia	88.15	10.23	0.44	–
Leone del Palazzo dei Priori di Perugia	91.34	7.54	0.77	–
Porta di San Zeno – Verona				
Formelle I° Maestro	90.86	6.49	2.49	–
Formelle II° Maestro	79.83	0.07	6.31	13.56
Cavalli di San Marco – Venezia	97.22	1.22	1.04	–
Ghiberti – Porta del Paradiso del Battistero di Firenze	93.7	2.2	1.3	1.8

RJG

F C Thompson and M J Nasir: The manufacture of Celtic coins from the La Marquanderie hoard. Numismatic Chronicle, 1972, 12, 7th series, 61–73.

The coins examined in this article are billon coins of the Iron Age Tribe of the Coriosolites, who inhabited the Armorican peninsula (modern Brittany). The method of casting the flans is described and full analyses are given of fourteen coins. Most of these contained 70–80% copper and 15–20% silver, with minor amounts of other elements.

Metallurgical examination showed that the blanks were reheated to red heat and struck, after which they cooled in the air. WAO

Halina Budzynska: History of the discovery and exploitation of Zloty Stok arsenic ores. *Przegl. Geol. 1972.* **20,** *(6), 282–9. (In Polish).*

A history of the mining and exploitation of the now abandoned (in 1961) gold-bearing arsenic ore deposits (loellingite and arsenical pyrites, both rich in Co, plus other associated minerals), located about 2 km from Zloty Stok in the north-east part of the Klodzko-Zloty Stok massif, and worked for more than 1000 years, is followed by an account of an experimental evaluation of the crucible roasting, chlorination, cyanide extraction, and iodine extraction methods of determination of the Au bound in the cinders remaining after As recovery.

P A Schubiger: Instrumental activation analysis of trace elements in Roman lead objects. *Report 1972, EIR–214, 112 pp from Nucl. Sci. Abstra. 27, No 4, p 7335 (1973). (In German).*

(Eidg. Inst. Reaktorforsch., Wuerenlingen, Switz.) Antique Roman lead objects were irradiated with neutron doses 10^{17} neutrons/cm^2 for 4 hours. The gamma spectrum was then recorded by Ge(Li) detectors and evaluated by computer; 75 objects were analysed for Sn, Au, Cu, As, Sb, and Ag. In comparison to Pb bars, Pb pipes contained significantly higher amounts of Sn and Au, while As, Sb, Cu and Ag were similar. It was assumed that the Romans intentionally added Sn to the Pb piping with Au as a fortuitous intrusion. It was impossible to distinguish between different mines on the basis of trace metal contents in lead bars.

Anon: Short notes on a famous bronze statue: the "Gattamelata" in Padua. *Fonderia, Feb. 1973,* 22 *(2), 67. 1 photo. (In Italian).*

The construction of a 15th century Italian equestrian statue is described. AHL

Bartlett H Wells: Knowledge of spring steel in Hellenistic times. *Journal of the Arms and Armour Society. March–June 1973.* 7 *(9/10), 249–251. 1 plate.*

Paragraphs 43 through 47 of the Belopoiika (Missile Weapons) of Philo the Mechanician of Byzantion, who flourished toward the end of the third century BC are translated through the German into English and commented upon. The passage describes the manufacture of springs from bronze and makes the earliest known mention of spring temper in steel, referring to the extreme resilience of the Celtic and Spanish swords of the period. MG

J N McGrath: A note on the classification of Celtic swords. *Journal of the Arms and Armour Society. March–June 1973.* 7 *(9/10), 263–265. 4 figs. (1 micrograph), 11 refs.*

The author proposes a system of classification of swords from the La Tène cultural periods according to a strictly metallurgical system, dividing them into two main classes, one of soft iron and the other of carburized steel. The latter is subdivided according to methods or their combination to produce hardness. One of these divisions may represent a link between the Celtic and the pattern-welded sword. There is also a table relating to La Tène culture phases of Déchelette with Piggott's classification system for Celtic swords of British provenance. MG

Karel Stransky and others: What was the prehistoric ring from the Bull's Rock in Moravia made of. *Slevarenstvi, 1973.* 21 *(9), 360–6. (In Czech.)*

The authors are with Vojenske Akad., Brno, Czech. In the structure of a ring fragment, mostly iron oxides, a small quantity of copper oxides, and traces of metallic copper and tin have been found. The Hallstatt ring from the Bulls Rock was most probably forged of steel with low carbon content. It is not a gray or white iron casting.

H Straube: Ancient steel production in the Kärnten Area (Carinthia). *Radex Rundschau. 1973 (2), 479–498. (In German). 54 refs.*

The production of iron and steel by the Romans is reviewed fully, and experimental work on shaft furnaces with supply of blast is reported. The view, widely held, that only carbonless iron could be made in the ancient shaft furnace and that conversion to steel required subsequent carburization is not supported by the present results. MG

Spyridon Marinatos: Excavations at Thera V; (1971 season). *Book. 'E en Athenais Arhaiologike 'Etaireia, Athens, 47 pp. 14 plates. 1972, 7 drawings and plans, 10 color plates, 114 photos. 150 drs.*

The results of the 1971 excavations at Thera (Santorini) are presented. On pp 34–35, spectrographic analytical data on a lead weight are given; the presence of antimony and silver in relatively large proportions (250 and 160 ppm respectively) indicate the age of the lead. AHL

Adam Mazur and Elzbieta Nosek. Metal examination of iron objects from Niani. *Materialy Zachodnio–Pomorski, 1971,* 17, *535–552. (In Polish). German summary, 23 illus. and drawings, 4 tables.*

The objects (mostly knives) are from excavations in the Republic of Guinea (Africa) and are dated at about 13–15th century AD. Microscopic examinations and chemical analyses were carried out. Cu, P, Ni, W, Ti and Mo (probably from ores) were found in different percentages as impurities. These results and the probable techniques are discussed. HJ

W A Oddy: Analyses of Lombardic tremisses by the specific gravity method. *Numismatic Chronicle. 1972. 7th Series.* 12, *193–215.*

Analyses have been carried out by the non-destructive specific gravity method of 89 gold tremisses of the Lombards. On the basis of the gold contents of the coins, a tentative subdivision of the six main classes into twelve groups is suggested. The results are presented graphically, and from the diagrams the process of debasement and weight reduction of the Lombard gold coinage during the seventh and eighth centuries can be followed. The tables of results form a corpus of almost all the Lombard gold coins in the public collections in England. WAO (AA)

K Bielenin: Ancient mining and iron metallurgy in the Holy Cross Mountains. *Warsaw and Krakow, 1974. Book, 179 pp. (In Polish).*

A detailed account of an area famous for its slag-pit shaft furnaces of the first 500 years AD. The author discusses the charcoal, ore, slag and the metallurgy of the products. Chapters include surveying slag block sites with a magnetometer. Air photos. Experiments on the process. Mine timbers.

Åke Hyenstrand: Iron and Settlement; studies on the older colonisation of Delarna (Järn och bebyggelse) Falun, 1974. *Book. (In Swedish).*

Deals with settlement in the Late Iron Age (500–1100 AD). This was an outlying area of Sweden at that time. Gives the results of an Inventory of Ancient Monuments 1963–1974.

Supplements Inga Serning's book of 1966. Surveys older literature on the subject (17–19th century). Estimates over 1000 sites of iron-making in the Viking and Wendel periods. Gives 32 C–14 dates from charcoal in the slag heaps.

A Steinberg: Joining methods on large bronze statues; some experiments in ancient technology. ***In*** **Application of Science in the examination of works of art.**
Ed. Wm. J Young. Museum of Fine Arts, Boston. 1973. pp 103–138.

A very detailed treatment of the subject with many micrographs and analyses. The alloys were mainly leaded bronzes and the "flow" welds were made by pouring superheated metal into prepared join areas controlled by moulds, and smoothing off surplus metal from the outside but often leaving it on the inside as reinforcement. This process could be repeated section-by-section to give an overlapping seam weld, each section being as much as 3 cm x 10 cm.

C Schaaber: Pliny's remarks on iron supported by metallurgical investigations. *Jahrbuch der Wittheit zu Bremen, 1974,* **18**, *215–245. (In German)*

Concludes that the Elder Pliny's Chapter 41 shows an accurate knowledge of Roman ironworking techniques. Schaaber shows this with the aid of finds from the Austrian site of Magdalensberg in Roman *Noricum*. He found it possible to trepan pieces suitable for metallurgical examination by spark erosion. Those in iron were up to 2 cm long x 3 mm diameter. The carbon content of a nail varied from 0.21–0.78%. Other finds included a quench-hardened steel chisel and cast iron with over 2% C and a 4 kg bloom containing some cast iron (ledeburite).

J W Butler: How Leonardo Solved a Casting Problem.
Foundry Trade Journal, 1974, **137** *(3028/9), 860.*

In 1482 the Duke of Milan commissioned Leonardo da Vinci to produce a bronze horse and rider as a memorial to his father. Leonardo completed a clay model of a horse which stood some 26ft high which was unveiled in Milan in 1493. Some of the artist's notebooks were re-discovered in the National Library of Madrid some 10 years ago and they contain notes of the method which was to have been used for casting the horse in bronze. From the full size clay model, a series of concave plaster moulds were to have been prepared. After lining with wax, a convex clay core would be moulded inside. Heating would bake the clay core and melt the wax. After cooling, the space between core and plaster would again be filled with wax. The surface of the new wax model would have been carefully finished and a new clay mould built over it. The wax would have been cleaned off, the mould re-assembled and the bronze poured in.

However, the project was cancelled, and the clay model collapsed and feel to pieces when used for target practice by the French archers who conquered Milan in 1499.

ASIA

D P Agrawal: The Copper/Bronze Age in India.
Book. Munshiram Manoharlal, New Delhi, 1971, 270 pp. Refs. Index. 22 figs. 32 tables.

Contents include an introduction and a description of the problems of Pre-Harappa cultures, the Harappa culture, other chalcolithic cultures, plus information on P G Ware and the beginning of N B P Ware. The book also includes chapters on: dating methods; the origins and diffusion of metallurgy; chemical analysis; and metal-forging techniques and typology. NH

T Asada and T Nakatsuka: Microanalysis of a Japanese temple bell cast in the eighth century.
In *Proceedings of the Sixth International Conference on X-ray Optics and Microanalysis, 1971–1972. 735–741. 19 photos, 2 tables, 1 diagram, 2 refs.*

The bell of Todai-ji Temple in Nara was subjected to electron probe X-ray microanalysis using a JEOL type JXA–3A instrument. The bell, which weighed 26.3 tons, was cast in 752 AD, while the pendant and washer were made in 1239 and 1513 respectively. All the samples were alpha-bronze and contained coarsely segregated lead, and to a lesser extent, iron; nonmetallic inclusions consisting of 0.6 $Cu_9 S_5$ plus 0.4 Cu S were observed. All parts also uniformly contained approximately 2–3% arsenic, approximately 1% silver and no zinc. Dendritic segregation of an alloy containing approximately 20% tin occurred in the cannon of the bell; the canon-contained about 83% copper and about 5% tin as opposed to about 90% copper and 0.6–1.9% tin in the pendant and washer. Photomicrographs of polished and etched specimens indicated a cast structure and showed no evidence of heat treatment; in the canons, some fracture striation due to regular striking was noted. Cobalt-60 gamma radiography revealed large cavities in the upper part of the canon. AHL

Takehiko Sakata and Daikaku Manabe: Ancient ironmaking in Tsukushi. I. Ruins of the Tatara furnace at Ito-Imazyuku and Mikasa-Kinome after a typhoon in the fourth century.
Kyushu Daigaku Kogaku Shuho, 1970, **43** *(4), 584–591. (In Japanese.*

The authors are with the Kyushu University Fukuoka, Japan. An archaeological study of the ancient iron making technologies in Japan.

Barbara Keyser: A technical study of two late Chou bronze Chien. *Bulletin of the American Institute for Conservation of Historic and Artistic Works. 1973,* **13**, *No. 2, 50–64, 8 refs. 6 figs.*

Techniques applied to the fabrication of a pair of late Chou Chien are considered. One is at the Freer and the other at the Minneapolis Institute of Art. The two Chien are described from a technical point of view and the elements of decor are analysed. An important issue is whether stamps in the positive were used to stamp the designs in the mould surface, or negative stamps were used to work them on the model. The probable procedure for the manufacture of the Chien is summarized.

Swarna Kamal Bhowmik: An analysis of some copper ore samples from Ambaji, Banaskantha District of Gujarat. *Museum Bulletin. 1970, 22, (Technical Issue), 145–152. 1 table, 9 refs. 1 plate.*

Subjects discussed include characteristic geological features associated with base metal deposits, evidences of ancient mining and metallurgy, chemical analysis, and conclusions. JEHS

Anon: An ancient Indian zinc retort. *In Fact. June 1971. (82). 1 photo.*

Zinc retorts from Zawar, India, believed to date from the thirteenth to the sixteenth centuries, were examined visually, using x-rays and by chemical analysis. The results are given and probable operating conditions suggested. AHL

K T M Hegde and S N Pandey: Chemical analysis of some copper objects from Mitathal. *Studies in Museology. 1970–72, 6–8, 42–5.*

Seven copper objects from an excavation at Mitathal (part of the "material remains of the Sothi, Sothi in association with Harappan, and late Harappan in association with Copper Hoard communities in stratified context") were analyzed chemically and it was found that copper in all objects amounted to more than 98% and that only a small quantity of iron and negligible quantities of nickel and arsenic were found. The analyses of the seven objects are given. NH

ASIA MINOR

A Steinberg and F Koucky: Preliminary metallurgical research in the ancient Cypriot copper industry. In *American Expedition to Idalion. Ed. L E Stanger, A Walker and G E Wright. Am. School of Oriental Res. 1974. pp. 149–178.*

Describes some crucible smelting experiments on oxide ores and gives a very complete list of all the analyses of Cypriot Cu slags at present published with the addition of 13 new ones made by XRF. Finds that the so-called "Phoenician" slags have a composition near the high-iron eutectic in the $FeO-SiO_2$ phase diagram (22–27% SiO_2) while the Roman-type are near the high silica eutectic (38% SiO_2). In the former the excess wüstite weathers to give the reddish brown colour of the "Phoenician" and and LBA slags, to be compared with the stable black of the Roman, which seem also to be tap slags.

AFRICA

J Vandier D'Abbadie and Felix Michel: Analysis of forty mirrors in the Department of Egyptian Antiquities of the Louvre Museum. *Annales du Laboratoire de Recherche des Musées de France. 1972. 34–46. Outlines, tables, 10 photographs, bibliography. (In French)*

The mirrors of the Ancient Empire are copper, those of later periods are generally bronze. The percentage of tin is high, near or over 10% in the bronze mirrors. Arsenic is present in important quantities in the copper mirrors. The lead percentage is not important. Zinc is absent with two exceptions; it is characteristic of ancient Egyptian metallurgy. LW (trans M.Br.)

David Crownover and William Kohler: Gold beads from the Gold Coast. *Expedition. Spring 1973, 15 (3), 25–29.*

This article includes a quotation from T E Bowditch. Mission from Cape Coast Castle to Ashantee (London, John Murray, 1819) of the details of the lost wax casting process then in use in Komasi, Ghana, for casting gold ornaments. A series of eight photographs show the process as practised in modern times. JW

AMERICA

Heather Lechtman: A Tumbaga object from the high Andes of Venezuela. *American Antiquity. 1973, 38 (4), 473–482.*

The complete study of a Pre-columbian metal artifact by wet chemical analysis, metallographic examination and electromicroanalysis, proved it to be a typical tumbaga alloy. It was made of extremely thin, cast sheet metal and was gilded by one of the processes of depletion gilding. Therefore the piece could not have been made locally. CLR

A P McCartney and D J Mack: Iron utilization by the Thule Eskimos of central Canada. *American Antiquity, 1973, 38 (3), 328–339. 6 figs. incl. 3 micrographs; 30 refs.*

Seven metal fragments were located in 1969 at the Thule Age (ca. 1200) site of Silumiut on the western coast of Hudson Bay, four of native copper and three of iron. No forming technique other than cold hammering appears in evidence. Almost no sources of metallic iron are found in the Canadian Arctic. Analysis of the three iron fragments could identify two with the Cape York (Greenland) meteorite. The third is a wrought iron of .06–.12% carbon content and represents the most southerly find of Norse iron (and the earliest radiocarbon dated) in the central area. A very long distance trade network for iron is seen to have existed 400 years before direct European contact. MG

TECHNIQUES

Karoly Marechal: Technology of casting bells. *Bányászati és Kohászati Öntöde. Jan. 1973. 24 (1), 1–7, 12 refs. (In Hungarian).*

The technology of casting bells from the medieval age to the present day is reviewed. The metals and alloys used, construction methods, and techniques and materials for mould-making are discussed in detail. MG

L B Hunt: The early history of gold plating.
Gold Bulletin. January 1973, 6 (1), 16–27.

The early history of gold electroplating, from 1803 to a about 1904, is described in detail. MG

Anon: Diffusion and precipitation of gold in lead.
Gold Bulletin. October 1973, 6 (4), 107.

Experiments on the mechanism of the diffusion of gold in lead are described. This is an account of work published in full elsewhere. WAO

K C Barraclough and K A Kerr: Metallographic examination of some archive samples of steel.
Journal of the Iron and Steel Institute. 1973, **211** *(7), 470–474.*

Three samples of steel from museum collections were submitted to a metallographic examination. These comprise a piece from the last blister steel production in England (1951), a historic specimen made specially in Sheffield in 1877 for the famous Dr Percy to elucidate his theory on the produciton of blisters in blister steel, and the only known sample of puddled steel still in existence, collected by Dr Percy in 1859 from the Ebbw Vale works. The experimental sample was produced by remelting wrought iron in a crucible to remove the slag and subsequently carburizing in the cementation furnace, no blisters appearing in this particular case. The micro cleanness of this sample is remarkably good (so much so that it is hoped in the near future to check a number of samples of crucible steel from the Percy collection to determine whether this is typical). The other two samples did, as was expected, contain a fair proportion of entrapped slag and the nature of this was examined. MG

P M Roberts: Gold brazing in antiquity. Technical achievements in the earliest civilisations.
Gold Bulletin. October, 1973, 6 (4), 112–119.

The author gives a clear discussion of brazing of gold alloys in antiquity and of the diffusion bonding or "autogenous welding" technique of joining gold alloys, particularly used for gold granulation and filigree. A number of objects are reproduced in colour: a double-walled gold vessel from the tomb of Queen Pu-Abi in the Royal Cemetery in Ur and a bowl from the same tomb with a close-up of the brazed joint, showing the fillet of brazing metal; the handle of the famous gold dagger of Tutankhamun; and of special interest, a small gold button from Thebes.

C R Schad and H Warlimont: The effect of the construction material on the sound of bells.
Acustica. 1973, 29 (1), 1–14. 18 refs (In German)

The tonal qualities of bronze were investigated as a function of alloy composition for five bells, containing Cu 75.3–80.9 and Sn 10.1–23.4%, (one bell containing Sb 10.8%). The effects of Sn and Pb content on the damping of acoustic vibrations of bronze were measured. Variations of the dimensions and the mass of the bells affected their sound to a greater extent than considerable changes in alloy composition. MG

Anon: The sources and composition of prehistoric gold: investigations by emission spectroscopy.
Gold Bulletin. April 1973, 6 (2), 51.

This is a long abstract of a paper (Angew. Chem. 1972, 84, No 14, p. 668) by Hartmann and Sangmeister on the large number of analyses of prehistoric gold objects. WAO

Zbigniew Brochwicz: Gilder's leaves in historical objects. Characteristics and methods of identification.
Materialy Zachodnio–Pomorskie. 1971. **17**, *623–681. (In Polish. German Summary) 23 illus.*

Gold, silver, tin, aluminium and brass ("gold metal") are considered. Details are given on the history of the applications, methods of production, properties of the metal, and colour characteristics. Methods of identification by spot-tests and microcrystallography are included. Chromatographic tests will be handled in another paper. HJ

Zbigniew Brochwicz: The bismuth technique.
Materialy Muzeum Budownictwa Ludowego w Sanoku. 1972 (16), 45–51. (In Polish with English and Russian summaries).

An imitation of a metallic surface is obtained by covering a white ground with powdered metallic bismuth and burnishing with agate. This in turn can be painted, punched, and thinly varnished. It was used to decorate small items of furniture, caskets, etc. The technique seems to have started in the 13th century, was well-developed by the 15th century (South Germany, Switzerland), but flourished mostly in the Renaissance and Baroque periods. No references can be found in old treatises and manuscripts. After 1880, the bismuth technique became forgotten and was reconstructed again by Sutter in 1920. Properties of bismuth and its compounds, and methods of identification are described. Precipitated bismuth is ground with a 5% solution of gelatine, painted thinly (2–3 times) over a white preparation (glue with alabaster, chalk, white bolus, or zinc white) and burnished when dry. The surface is very sensitive to H_2S, water and abrasion. Painting of ornaments (tempera medium) has to be done very carefully. As a protective varnish, weak solutions of polystyrene in toluene or of natural resins in toluene or benzene should be used. Yellow-tinted varnishes do not give the effect of gold. Ground metallic Bi can also be used as a pigment, but the effects are not the same as with precipitated bismuth. Tin is not good for this technique; however, antimony is under investigation. HJ

Annual meeting notes

Unconfirmed Minutes of ANNUAL GENERAL MEETING held at 11.00 am at Caer Llan Field Centre, Monmouth, on Saturday, 3 May 1975. 53 members were present the Chair being taken by Dr R F Tylecote

1. **Apologies for Absence** were received from Messrs Lethbridge, Morgan Rees, Davis, Morton, Butler, Raphael, Shore, Moffat, Allen, Haynes and Knight, Dr Mutton, Professor Nutting and Mrs Lang.

2. **Minutes of the Last Annual General Meeting** were read by the Honorary Secretary and were accepted as a true record.

3. **Matters Arising from the Minutes.** No matters were raised.

4. **Chairman's Report.** The Chairman referred to a further successful year and thanked his Committee for being so helpful and making his task so easy.

5. **Hon. Secretary's Report.** ;The only milestone we had passed was the recognition of the Society as a Charity. He pointed out, however, that the Hon. Treasurer has been of great assistance to him in the work of running the Society.

6. **Hon. Treasurer's Report.** It was reported that funds were up by £220 and that £500 more had been transferred to Bonds which now yielded 9½%. It was Society policy that the AGM and Annual Conference should be self supporting, other than for payment of the accommodation for the AGM and this had been achieved. We continued to pay the CBA insurance policy to cover our members on visits. We had contributed £50 to the G R Morton (Ironbridge) Fund and had provided three grants to aid research work. We had also commissioned an English translation of a report on Swedish Blast Furnaces and had sold this to Jernkontoret, who in turn had provided copies of the printed English version which were now available at £1.25 per copy.

In view of the postage increases and the fact that we would in future have to pay for camera copy for the Journal (£180 in the current year and £260–£300 in 1976), the Hon. Treasurer was proposing that subscriptions be increased from 1st January 1976 as follows:–

Ordinary Members	£2.50 per annum
Ordinary Members who are also Members of the Metal Society	£2.00 per annum
Family Subscription	£3.25 per annum
Metals Society Family Subscription	£2.75 per annum
Retired Members	£1.50 per annum

These proposals were seconded by Professor Tucker, who considered they still offered very good value, and were carried without dissent.

The Hon. Treasurer proposed adoption of the accounts, which was seconded by Mr Darby and carried unanimously.

Mr Darby raised the question of covenanting subscriptions since we were now a registered Charity; this was amplified by Professor Tucker and the Hon. Treasurer agreed to investigate the position.

7. **Hon. Editor's Report.** Apologies were made for some errors in Vol. 8, Part II. It was hoped Vol. 9, Part I would be available at the Conference and Vol. 9, Part II before the end of the year. The Index to Vols. 1 to 7 would also probably be available at the Conference; a charge of 50p. would be made for this (£1.00 to non-members). The Hon. Editor expressed his gratitude both to Mr R Day and to the Printing Section of the Metals Society.

Mr Doncaster expressed his opinion that the Journal wass too technical; in addition the subject matter of the Conferences was not really covered. Mr Berg agreed with these sentiments; Miss Chatwin felt that the Conference and the Annual General Meeting should be reported in the next issue subsequent to them being held if the reports were to be of any real use. The Editor felt that Conference papers were published where appropriate – there were none from Sheffield, however, although Conferences had received preprints; he would, however, endeavour to meet these wishes in future. In response to another enquiry, he expressed his opinion that mining and mining techniques did not really fall within the scope of the Society's publications.

8. **Election of Officers and Committee**

The following were unanimously elected:–

President	Dr N Swindells (to 1977)
Chairman	Dr R F Tylecote (to 1976)
Hon. Secretary	K C Barraclough
Hon. Treasurer	C R Blick
Hon. Editor	Dr R F Tylecote

General Members of Committee:–

D W Crossley and Prof D G Tucker (to 1976)
W K V Gale and W A Oddy (to 1977)
F A Batty and R Day (to 1978)
T Berg and Dr N Mutton (to 1979)

The Chairman proposed a vote of thanks to the retiring President, Prof H O'Neill, for his invaluable services over the past two years and also to the two retiring members of Committee – Mr M Hallett and Mr B Hardman.

Representatives on other bodies were confirmed as follows:

The Metals Society	Dr N Swindells (ex officio)
Royal Anthropological Institute	Mr B E Fagg
Council for British Archaeology	Mr D W Crossley

9. **Appointment of Honorary Auditor.** It was unanimously agreed that Mr John Widdop be asked to continue as Hon. Auditor.

10. **Annual Conference, 1975.** The Hon. Treasurer detailed the arrangements which he undertook to circulate in the near future, together with the optional extension to cover the two blast furnaces further north.

11. **Future Meetings.** The idea of an Annual General Meeting to be held in London was put to the meeting and received general support; the Hon. Secretary agreed to investigate the possibilities.

It was reported that tentative arrangments had been put in hand for a Conference in the Cleveland area in 1976.

12. **Other Business.** Mr Darby expressed gratitude to the Society on behalf of the Ironbridge Gorge Museum Trust for the donation made to the G R Morton Fund. He also thanked the Officers and Committee for the able manner in which the Society had been run over the past twelve months, and requested that these sentiments be recorded in the Minutes. His motion was carried unanimously.

HISTORICAL METALLURGY SOCIETY

RECEIPTS AND PAYMENTS ACCOUNT - 1974

RECEIPTS

Balance brought forward from 1973 Account			495.09
Subscriptions:	1973	25.30	
	1974	417.33	
	1975	13.50 *	
	1976	3.00 *	459.33
Donations			11.60
Sales of back numbers of Bulletins and offprints			103.89
AGM Ironbridge 1974 Receipts			96.00
Annual Conference – Sheffield – 1974 Receipts			1 031.21
			£2 197.12

*These amounts will not be taken into 1975 account.

PAYMENTS

CBA	Subscription	6.00	
	Insurance Policy	14.75	20.75
Ironbridge Gorge Museum			
	Subscription	3.00	
	Reg Morton Fund	50.00	53.00
Editor's Expenses			52.97
Hon. Secretary's Expenses			3.76
Hon. Treasurer's Expenses			5.00
Postage Account			133.65
Advertisement			18.00
Index			70.00
Cost of reprinting back numbers of Bulletin			15.26
Transport – Journals from London			5.18
AGM Ironbridge 1974	Meal	97.53	
	Coaches	20.00	
	Room, Coffee	7.71	125.24
Annual Conference – Sheffield – 1974			
	Accommodation	850.98	
	Coaches	50.00	
	Gratuities	6.00	
	Printing and Pamphlets	75.84	
	Projection	10.00	
	Postage	7.62	
	Abbeydale Industrial Hamlet	21.00	1 021.44
Transfer to Deposit account			500.00
Balance at Bank – 31st December 1974			172.87
			£2 197.12

Chairman

Treasurer

Audited and found correct February 5, 1975

Hon. Auditor

RESEARCH AND PUBLICATION ACCOUNT 1974

RECEIPTS

Balance at Bank – 1 January 1974	232. 82
Jernkontoret, Stockholm – Translation	50. 00
Dividends ex British Savings Bonds	31. 38
	£314. 20

PAYMENTS

Grants		
Dr R F Tylecote	25. 00	
Mr D W Crossley	30. 00	
Chichester Civic Society	25. 00	80. 00
Transferred to Deposit Account		100. 00
Balance at Bank – 31st December 1974		134. 20
		£314. 20

ACCUMULATED FUNDS AS AT 31st DECEMBER 1974

£500 8½% British Savings Bonds	500. 00
Research and Publication Account	134. 20
Receipts and Payments Account	172. 87
Deposit Account	640. 30
	£1 447. 37 (1973: £1 227.91)