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Sidney Gilchrist Thomas

From an unfinished crayon drawing in the National Portrait Gallery

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The pursuit of crotchets

An Appreciation of Sidney Gilchrist Thomas on the Centenary of the Publication of the Basic Process for Steelmaking

*S G Denner**

Summary

Sir Henry Bessemer, the inventor of the first pneumatic steelmaking process, has been called the accoucheur of the Age of Steel. By the same token Sidney Gilchrist Thomas, the chief architect of the basic process, can be classed as the 'district nurse' in that he not only recognised the main problem with Bessemer's 'baby' but also cured it. This appreciation looks briefly at the life and works of Thomas and examines his important contributions to both Metallurgy and Agriculture.

Introduction

In March 1875, Sidney Gilchrist Thomas wrote a letter[1] to a female acquaintance in which he rhetorically questioned whether Life was ought but the pursuit of crotchets with the pursuit being the best part. One of the most technologically significant crotchets at that time was the dephosphorisation of pig iron in the Bessemer converter. In 1875, Thomas believed (correctly, as it transpired) that he had a theoretical solution to this problem but the public announcement of his process was delayed, for want of experimental verification, until 1878. It is thus one hundred years from the publication of a process which was to have a galvanising effect on the steel industries of the world and which undoubtedly played a major role in the industrial development of many countries, particularly those of Western Europe. The time is, therefore, opportune to remember this great public benefactor who died of emphysema at the early age of thirty five.

Early Life

Sidney Gilchrist Thomas, the second child of William Thomas and Melicent Gilchrist, was born in London on the 16th April, 1850. As a child, Thomas was educationally precocious and at an early age decided to pursue a scientific career. At the age of 16 he changed his mind and, much to the chagrin of his parents and the headmaster of Dulwich College, where he was educated, resolved to matriculate at London University and read Medicine.

The choice of this profession possibly derived from a desire to emulate his elder brother, Llewellyn, but more probably had root in his already well-formed humanitarian principles, for he wrote six months before his death:

> "An old idea of mine was that the best way to get at people and move them for their own and the general advantage, was as a doctor, a position which if honourably and generously filled, gives a position and right to advise which none other can."[2]

In the event Thomas was prevented from pursuing a medical career. In 1867 William Thomas died of apoplexy and to ameliorate the financial burden on his mother, Thomas elected to enter the Civil Service. With the aid of his cousin, the vicar of Llandrilos, he was appointed Clerk to the Magistrates at the Marlborough Street Police Court; in 1868 he was transferred, at his own request, to the 'seedier' Thames Police Court, where he remained until May 1879.

Thomas tackled his new job enthusiastically and soon showed great ability: this is shown by testimonials reproduced in the volume written by his sister.[3] This training stood him in good stead when, in the late 1870's, the patent position of his process was attacked in the court rooms of England and Germany. In these cases, he was able to advise his lawyers on some points of patents law.

Thomas, however, did not relinquish his first love, Science. In 1868 he began studying in the evenings and experimenting at home. He also attended lecture courses, one of which was to prove of immense importance. In 1870, Thomas studied Chemistry at the Birkbeck Institute and on one occasion the lecturer, George Challenor, remarked that:

> "The man who eliminated phosphorus in the Bessemer Converter would one day make his fortune."[4]

This statement struck a favourable chord in Thomas who determined to solve the problem.

The Basic Process for the Dephosphorisation of Pig Iron

Until the late 1850's, the main structural materials available for engineering purposes were cast iron and wrought iron, the latter being produced using the puddling process invented by Henry Cort in 1784 and perfected by Joseph Hall in 1820. This process, the precursor of the Siemens–Martin open hearth process, eliminated substantially all of the carbon, silicon and manganese in addition to most of the phosphorus from pig iron. The main disadvantage of the puddling process were that it was both laborious and inefficient: only six ¼ ton charges could be handled by each puddler in a twelve hour shift.[5] In addition, a form of steel was produced but its use was restricted to the manufacture of small items such as tools and cutlery, the cementation and crucible processes being used. This material was extremely expensive.

This situation was altered dramatically when in 1856, Mr (later Sir) Henry Bessemer succeeded in removing the impurities from pig iron by blowing air through the molten charge. This process produced steel which was 20% of its previous price but, more importantly, enabled it to be produced in tonnage quantities. This was a most important step forward because it meant that a structural material became available which was superior to wrought iron but less expensive and restricted in use than crucible steel. Bessemer announced his invention on the 11th August 1856 to the British Association meeting at Cheltenham and following the meeting, was inundated with requests to operate the process.

However, the licensees who began using the process encountered a few fundamental problems. The most important of these was brittleness in the steel they produced owing to the presence of phosphorus. In his original experiments, Bessemer had employed low phosphoric pig iron and, in good faith, had announced his process as being applicable for all grades of pig iron.

The oxides of phosphorus are not as stable as those of iron so that all of the phosphorus originally present in the iron ore remains in the pig iron from the blast furnace. Despite much effort. Bessemer was unable to remove the phosphorus from pig iron and was eventually reduced to employing high grade ores from such countries as Sweden and Spain. Such action meant that the vast deposits of phosphoric ores of Luxembourg/Lorraine as well as those of Cleveland were not available for steelmaking using the Bessemer process. At the time, reasons for the non-removal of phosphorus were sought from analogy with the puddling process where up to 80% of the phosphorus was removed. It was considered that the higher finishing temperature of the Bessemer process vis a vis puddling ($\sim 1600^{\circ}$C cf 1300°C) or the shortness of the Bessemer operation (15-20 minutes) were perhaps significant. As Thomas later pointed out, if these reasons had been valid then there would have been little hope of ever achieving dephosphorisation.

Thomas, however, was looking at this problem from a chemical viewpoint. After careful study, he postulated that the phosphorus in the pig iron was oxidised along with the other impurities. However with a siliceous slag at the high temperatures involved, any phosphates formed would dissociate and the phosphorus pass back into the steel; that is to say that the chemical potential of the phosphorus in such an environment is lower in the steel than in the slag. Successful dephosphorisation could, by this argument, be achieved by raising the chemical potential of the phosphorus in the steel or lowering it in the slag. The most efficacious method of achieving this would be to lower the chemical potential of the phosphorus in the slag by utilising the well-known affinity between P_2O_5 and strong bases such as lime or magnesia. However, this reasoning led to a practical problem since the addition of lime to a Bessemer converter lined with siliceous bricks would have had drastic consequences since the lime would have chemically attacked the lining. The problem therefore crystallised into a search for a lining which would resist the attack of lime at high temperatures.

Thomas began experimenting in his home-made laboratory using a miniature crucible lined with limestone bricks but soon realised that more extensive trials of his theory were required. In 1876, he succeeded in eventually persuading his cousin, Percy Gilchrist, who was works chemist at Blaenavon Ironworks to become involved and for the next two years, the pair of them devoted much time to the search for a suitable lining material with Thomas spending most weekends in Wales. Eventual success was attained using fully shrunk dolomite bricks with tar as the binder. In the interim sufficient work had been accomplished to enable Thomas to announce to the Spring meeting of the Iron and Steel Institute, 1878:

> "It may be of interest to members to know that I have been enabled . . . to remove phosphorus entirely by the Bessemer Converter."[6]

To this statement, no comment was the stern reply: as Jeans[7] has noted:

> "The meeting did not laugh at the Youthful Eureka, nor did it congratulate the young man on his achievement, much less did it enquire about the method of elimination."

Such reactions did not unduly perturb Thomas who, with Gilchrist, prepared a paper entitled 'On the Elimination of Phosphorus in the Bessemer Converter' for presentation at the Autumn meeting of the Iron and Steel Institute held in Paris to coincide with he Great Exhibition of 1878. The importance of this paper, however, was not recognised and the reading of it was postponed until May 1879. The meeting in Paris,was, nevertheless, far from being a total failure for Thomas as a result of contacts which he made on the visit to the Creusot Works which had been arranged as part of the programme. On this visit, he succeeded in gaining the attention of E Windsor Richards, then the General Manager of Bolckow, Vaughan and Co Ltd, Bolckow, Vaughan's of Middlesbrough in Cleveland had one of the largest steel mills in the world but were unable to exploit the Bessemer process using the native ores since these had too high a phosphorus content. Richards was sufficiently impressed with Thomas' work that he persuaded his directors to allow him to investigate this work further. To this end, Richards observed some plant trials at Blaenavon and Dowlais and was sufficiently convinced to arrange further trials at Middlesbrough using a 1½ ton converter. These trials succeeded in removing various problems and the first 'official' blow in a basic Bessemer converter was carried out on April 4th, 1879.

After the presentation of the paper at the May meeting:[8]

> "Middlesbrough was besieged by a large array of Continental metallurgists, and a few hundredweight of basic bricks, molten metal used and steel produced were taken away for searching analysis at home."[9]

The process was an immediate success and licences were granted or patent rights sold to numerous ironworks, particularly those of Western Europe. The problem of dephosphorisation was not nearly as acute in the United States since the vast deposits around Lake Superior were low in phosphorus. Nevertheless, the increasing costs of mining the Lake Superior ores prompted Andrew Carnegie to attempt to procure the Thomas franchise to operate the process at his Edgar Thomson works: suitable basic ores were available nearer to the Monanghela River Bank site. Carnegie was not prepared to pay Thomas' asking price ($ 300,000) but, acting as Thomas' agent, he was able to persuade the Bessemer Steel Association, of which he was a member, to purchase the patents. In recognition of his:

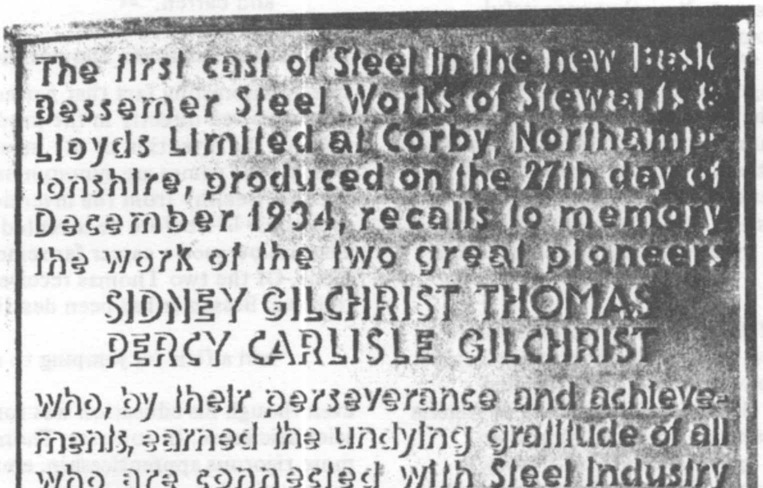
> "generosity in introducing the Thomas basic process to the US and in making it available to the entire Bessemer Steel Association,"[10]

Carnegie's company was not assessed any portion of the purchase fee; Thomas also paid a commission of $ 50,000 to Carnegie. Hence Carnegie received a handsome sum of money for operating the Thomas process free of charge.

The adoption of the basic Bessemer process was slower in the UK than elsewhere. This was, in part, the result of greater conservatism (the Bessemer debacle had produced numerous enemies of pneumatic steelmaking) and partly that the British phosphoric ores with their high silica, sulphur and alumina and relatively low phosphorus contents were less suitable than most of the phosphoric ores of, for example, Germany. Nevertheless, even in the UK, steelmaking patterns altered dramatically after the introduction of the basic Bessemer process. In 1878, the total steel production in the UK was 981,686 tons, only 20 tons of which were produced using the basic process.[11] In 1880, this latter figure had increased to 10,000 tons and in 1890, approximately 500,000 tons of basic steel were produced in the UK.[12] In addition, it became clear in the 1880's, as Thomas had suggested, that the underlying philosophy of the basic process (lime additions and basic linings) could be applied to open hearth steelmaking; the first basic open hearth furnace was constructed in the UK at Brymbo in 1884.[13] With the greater control over composition that this process afforded and since a charge containing significant proportions of scrap could be employed, basic open hearth steelmaking gradually superseded basic Bessemer steelmaking. In 1911 Bolckow, Vaughan ceased production of basic Bessemer steel in favour of the open hearth process.[14] In a leading article on this decision, 'The Iron and Coal Trades Review' remarked:

> "We are on the eve of, if we have not already reached, practically the end of the Bessemer process as an important factor in the steel trade of this country."[15]

This view was slightly premature because with improved blast furnace control and mixer car practice, there was a resurgence of interest in the Bessemer process in the 1930's. During this period, Stewarts and Lloyds constructed a Bessemer shop at Corby, Northants. This shop was constructed by German workers and a plaque (shown below) commemorating the achievements of Thomas and Gilchrist was produced from the new plant's first cast. The era of the Bessemer furnace was, in fact, relatively long for it was not until 1972 that the last Bessemer converter in the UK was blown. The disappearance of the Bessemer furnace will soon be followed by that of the open hearth furnace. Nevertheless, the principles of the basic process are applicable to the more modern steelmaking processes so that it is not inconceivable that posterity will pay greater regard to Thomas than to Bessemer.



The first cast of Steel in the new Basic Bessemer Steel Works of Stewarts & Lloyds Limited at Corby, Northamptonshire, produced on the 27th day of December 1934, recalls to memory the work of the two great pioneers

SIDNEY GILCHRIST THOMAS
PERCY CARLISLE GILCHRIST

who, by their perseverance and achievements, earned the undying gratitude of all who are connected with Steel Industry and Agriculture. In the Spring of the year 1879 the first charge of Steel was successfully produced by their new Basic Process in Middlesbrough-on-Tees. On the present occasion of the re-introduction into Great Britain of the Basic Bessemer Process the GUTEHOFFNUNGSHUTTE OBERHAUSEN A.G., OBERHAUSEN, Rhineland, wish to congratulate the Originators on the important step taken in fulfilment of an ideal as represented by the Corby Plant and to express their appreciation of having been entrusted with creative collaboration in its erection. May the Plant and its Workers enjoy a prosperous future to the benefit of their Country.

Basic Slag

Any discussion of the work of Sidney Gilchrist Thomas would be sadly incomplete without mention of the utilisation of basic slag, a topic which occupied the greater part of the last four years of his life.

Ever since Bessemer had invented pneumatic steelmaking and the resultant difficulties with dephosphorisation appreciated, it had been recognised that a process designed to remove the phosphorus would be doubly beneficial in that the phosphorus might be recovered and used as an agricultural fertilizer. The financial benefits that this entailed were considerable; for example, the phosphorus in the iron ore mined annually in Cleveland alone was worth more than £250,000, if it were to become available as a manure.[16] This knowledge had certainly not eluded Thomas but he was at great pains to appear ignorant. The following letter which he wrote to Gilchirst indicates his anxiety:

> "I don't want anyone more than is absolutely necessary to know it is even contemplated to utilise slag; as if we keep it quiet, we may by a clause in licenses get it all in our own hands."[17]

In such actions, Thomas was not altogether successful, although he did arrange to purchase some quantities of slag. On numerous occasions, he was frustrated in his efforts by the attitudes of works managers who were unable to visualise the economic potential of the so-called waste products: Bolckow, Vaughan's for example, arranged to sell their future slag production to German buyers for what amounted to a nominal sum. Thomas prevented a similar contract being negotiated by the North Eastern Steel Company of which he was a major shareholder, by threatening to sell his stake in the company.[18]

In 1882 the fragile health of Thomas began to deteriorate rapidly and the major burden of the extension of the basic process fell to Gilchrist. Thomas, meanwhile, travelled widely in search of a milder climate before settling in Algeria in 1883. The question of basic slag occupied him to an increasing extent and he set up a makeshift laboratory in order to carry out his researches. The prevailing agricultural thought in 1880 was that the phosphoric acid present in basic slag as insoluble phosphates would only be effective as a fertilizer if these phosphates were rendered soluble in the earth. Thomas experimented with chemical means to overcome this problem. He invited Gilchrist to participate in the scheme and also in the larger project, the manufacture of soda, because:

> "The more close I examine the salt position, the more clearly do I realise that steel will become a by-product in the manufacture of soda and soluble phosphates."[19]

Despite Thomas' great belief:

> "I see it as plainly as I saw the basic process – or even more plainly than I saw it."[20]

Gilchrist felt himself sufficiently committed in other directions to preclude his involvement in these projects. Thomas, however, persevered and engaged a number of chemists to work on this problem under his direction.

The credit for the first successful utilisation of basic slag for agricultural purposes, in fact, belongs not to Thomas but to Germany. Here, the simple expedient of finely grinding the slag and applying it directly to the land was devised. Thomas was informed of this success three months before his death and, with characteristic largesse, was undismayed. This magnanimity possibly derived from an 'I told you so' attitude since he had proposed this solution as early as 1880, but had been assured by British agricultural chemists that it would not work. In any case, the German success vindicated Thomas' faith in the usefulness of basic slag.

Thomas maintained an engrossed interest in slag up until the very end, and one of his last pleasurable acts was the receipt of a telegram communicating results. Unfortunately, he died before completely successful use of basic slag had been achieved; had he lived but two further years he would have learned that 300,000 tons of basic slag were applied to German soils in 1887. The German lead was soon followed in the UK and the efforts of Thomas on behalf of Agriculture were summarised poetically by Sir Thomas Middleton when he wrote to Lilian Gilchirst Thompson:

> "Your brother's work certainly deserves to be remembered, for it has done much to justify Blake's view of England. There are great stretches of grassland up and down the country now "green and pleasant" which but for the Thomas-Gilchrist process and its resulting slag would still be brown and barren."[21]

Thomas the Scientist: Thomas the Man

It is an interesting fact that neither Bessemer nor Thomas were involved directly in the production of iron and steel prior to the invention of the steelmaking processes with which their names are synonymous. Bessemer had already become wealthy from the invention of a variety of processes[22,23] before he invented pneumatic steelmaking; Thomas pursued a career far removed from the industrial scene. Of the two Thomas received the more formal scientific training. Bessemer has been described as having:

> "had a flair for jumping to correct conclusions,"[24]

even though his education was somewhat deficient in a scientific sense. In contrast, Thomas, having received the more rigorous apprenticeship, employed his knowledge systematically.

It has already been indicated that Thomas launched, early in life, into the double pursuit of scientific student and legal clerk. Mention has been made of his studies at Birkbeck Institute; he went further and obtained the credentials of a practical chemist by passing all of the examinations of the School of Mines that were open to him as a part-time student. In later life, he suggested that he had done this to obviate dismissal of his ideas for lack of formal qualifications. That he intended, at some stage, to employ his knowledge in a full-time scientific career is irrefutable: he had applied for the position of Works Chemist at Blaenavon Ironworks but his cousin, Gilchrist, was preferred since he was a 'practical chemist'. Thomas was refused Fellowship of the Chemical Society in July 1876 on similar grounds, although he was elected eleven months later.

There is good evidence that Thomas approached his work on dephosphorisation in a scientific and logical fashion. It is recorded[7] that he would examine all the relevant literature and, using inductive reasoning, would assemble the observed facts around three or four central themes in order to construct a hypothesis to explain the observations. Having postulated the reason for the non-removal of the phosphorus, namely the acid nature of the slag, experimental observation was evidently required to verify or refute his ideas. His original experiments were pursued enthusiastically: one anecdote has it that in his zeal he twice set fire to his rooms.[25] In this work, he must have achieved some proof of the correctness of his theory but, unlike Bessemer, did not stop at this point. Although enough data had been accumulated to justify his beliefs, Thomas realised the need for information which could be applied industrially and he recognised that this could only be obtained with the aid of others; hence, the involvement of Gilchrist. In the publication of the basic process, Thomas also 'trod carefully' in that he only gave details after extensive plant trials and when all sources of possible contention had been studied this may have been a reaction to the misadventure suffered by Bessemer.

Despite his formal approach to scientific work, Thomas has often been described as an 'amateur scientist'.(see eg ref 25) Doubtlessly, the term has been applied in a romantic sense, but, unfortunately, it also implies a degree of dilettantism which in the case of Thomas, could not be more spurious. Although he is primarily remembered for basic steelmaking, Thomas had other scientific interests and contributed about three dozen articles, letters and reviews to the magazine, 'Iron' (edited by George Challenor) ranging in content from 'Pollution of Rivers and its Prevention' to 'Magnetism of Electricity'.[26] He was not interested in the pursuit of scientific knowledge merely as an intellectual exercise; he was continuously pressing for the application of scientific principles to industrial processes. In this pursuit he was especially well qualified since he was aware of the financial and legal aspects of industry in addition to the scientific features. On his arrival in New York in 1881, the magazine, 'Iron Age' noted that:

> "Though appearing to be rather a scholar than a man of business, his familiarity with the practical details of his profession . . . efface the first impression. More perhaps than any other man now living, Mr Thomas represents a class of inventors to whom the future belongs, and his success is a striking instance of the correctness of the principles which have guided his work."[27]

Many inventors contemporaneous with Thomas worked alone whereas Thomas did not. To ignore the roles of other individuals in the development and commercial exploitation of the basic process is to miss a most significant aspect of the way in which Thomas exercised his talents. As pointed out by Mitchell[28], the basic process did not result from the efforts of one man, but was founded on inspired team-work, the positions and abilities of the individual team-members being closely dovetailed. Percy Gilchrist, E P Martin and E Windsor Richards all made contributions of inestimable value as did John Stead, the metallurgical consultant of Bolckow, Vaughan and company. Stead is widely believed to have suggested the requirement of the after-blow wherein most of the phosphorus is removed. Stead modestly declined this honour, maintaining that its necessity was implicit in the Thomas-Gilchrist papers. The social status of these individuals was, in general, greater than that of Thomas. Nevertheless, Thomas was able to motivate them and not only in the case of the basic process itself but also in other enterprises. To do so required a strong character, a determined will and appreciable personal charisma. It is therefore of some interest in concluding this article, to examine Thomas, the man.

In scrutinising the personality and character of Thomas it is, unfortunately, difficult to be objective since the only contemporary biographies, those written by his cousin[1] and sister[2], are naturally biased and speak of him in almost reverential terms. Nevertheless, the views of such diverse individuals as Carnegie[10] and Gladstone[29] confirm closely the views of Thomas' relatives. For example, Burnie wrote:

> "No-one with the slightest faculty of observation could ever have come into contact with him and have failed to recognise a mind of exceptional power."[30]

and in the same vein, Carnegie recalled:

> "The first thought that passed through my mind when I saw him was 'He's a genius' ".[32]

Even from a distance, Thomas was indeed striking. His exagerated forehead, clean shaven – almost boyish – face, rather long hair and careless dress all no doubt contributed to his being called a 'pale Gladstonian youth'.[31] His spare frame was perhaps conditioned by his eccentric dietary habits: he rarely ate a midday meal. Nevertheless, he took great delight in walking and the rapid transition from the youthful rambler to the crippled young man is especially disturbing to contemplate.

His behaviour was ascetic and the regimes to which he subjected himself undoubtedly contributed to his physical deterioration. This was further exacerbated by his refusal to relax. His reasons for his continued involvement in such topics as basic slag were explained when he said:

> "I must, if I live, show that I can work at other things besides dephosphorisation."[32]

Such a reaction is understandable, even commendable. However, the cause of the compulsion is important in terms of the man's character.

Unlike Bessemer, Thomas was not interested in the improvement or invention of processes for their own sake. The motivating force behind him was much more basic, namely the acquisition of wealth; not for himself, but for the social changes which money could help to bring about. He was, by all accounts, a man of intense thrift (for example, the dephosphorisation process was largely financed by savings which he had accumulated from his meagre salary; savings only accumulated after strict self denial) and could have easily lived comfortably on the proceeds of his work. Yet Thomas had in mind quite grandiose schemes and required a large amount of money to finance them. From his earliest teenage years, Thomas had held radical opinions.

Throughout his life he remained faithful to these views and was dissatisfied with the law and the then 'present order'. His socialist philosophies were well summarised in a letter[33] to an old friend in which he advocated such policies as subsidising hospitals, schools, parks, museums, etc in addition to the abolition of hereditary priveleges and distinctions. His financial involvement in such schemes was curtailed by his early death. Notwithstanding this, the legacy of his estate was disposed of in a manner of which he would have undoubtedly approved: his sole executrix, his sister Lilian, shared his views on the use of money and disposed of the money as she was bade in 'doing good discriminately'. Causes which benefitted included improvements in working conditions in the East End of London, Suffragism and Worker Dwellings.

In it perhaps unfortunate that thrifty men are often portrayed as misers. In Thomas' case his thrift only extended to his personal requirements and it is reported that he was extremely generous to acquaintances. Thrifty men with a vision of how to improve conditions in society are pictured often in an even more unfavourable light being imagined as harsh, stern, even rebarbative. In the case of Thomas such images are counterfeit even though at times he displayed these characteristics.

In his personal relations his character took on a lighter hue. Although, according to report, he could occasionally be proud, petulant, cunning, stubborn or irritable the broad sweep of the canvas reveals a very different picture. As Burnie wrote:

> "habitually he was the most cheerful, the most fascinating, even the most humorous and lightsome of mortals."[34]

In general, it is this joie de vivre which characterised Thomas' writings. His almost puckish sense of humour found no greater expression than in the letters to his aunt with their juxtaposition of English and German phrases and in his communications from America which related his amusement at his importance in others' eyes.

Thomas' influence over his contemporaries undoubtedly arose in part from these winning aspects of his personality. Some contemporaries appear to have found even stronger reasons for their admiration; Carnegie was able to say:

> "He wears no title, but we felt we had one of the great men of our generation as our guest."[31]

This eulogy suggests an element of nobility and to many of his close associates Thomas was, indeed, a noble man. The writer of the above eulogy expressed this more forcefully when he wrote:

> "He has done more for England's greatness than all her kings and queens and aristocracy put together."[31]

Concluding Comments

Sidney Gilchrist Thomas died on the 1st February 1885, after a long illness and was buried at the Passy cemetery in Paris. Until very recently, his grave lay neglected; this is probably as he would have desired since he was never impressed by the accolades of fame.

It is a common practice to examine an individual's works and to pronounce a moral thereon. In this respect, the words of Thomas' cousin, written nearly 90 years ago, are very relevant; he wrote:

> "No moral needs to be tagged to a memoir of Sidney Gilchrist Thomas. His is a life which speaks for itself."[35]

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REFERENCES

1 R W Burnie, 'Memoir and Letters of Sidney Gilchrist Thomas – Inventor', John Murray, London, 1891, p48.

2 Lilian Gilchrist Thompson, 'Sidney Gilchrist Thomas – An Invention and its Consequences', Faber and Faber, London, 1940, p292.

3 ibid, p41.

4 R W Burnie, loc cit, p30.

5 J Dearden, 'Iron and Steel Today', Oxford Univ. Press, London, 1939, p29.

6 Lilian Gilchrist Thompson, oc cit p121.

7 W T Jeans, 'Creators of the Age of Steel', Chapman and Hall, London 1885.

8 S G Thomas and P C Gilchrist, 'On the Elimination of Phosphorus in the Bessemer Converter', J Iron and Steel Inst, 1879.

9 E Windsor Richards, Presidential Address, Cleveland Institution of Engineers, 15th November, 1880.

10 J F Wall, 'Andrew Carnegie', Oxford Univ Press, New York, 1970, pp500–504.

11 Lilian Gilchrist Thompson, loc cit p272.

12 F W Harbord, 'The Thomas-Gilchirst Basic Process, 1879–1937', J Iron and Steel Inst, 1937, 77p

13 H W Carr and W Taplin, 'History of the British Steel Industry', Basil Blackwell, Oxford, 1962, p103.

14 ibid, p215.

15 'The Decay of the Bessemer Process', Iron and Coal Trades Review, 1912.

16 I Lowthian Bell, 'Chemical Phenomena of Iron Smelting' J Iron and Steel Inst, 1871, (I), pp85, 277: 1871, (II), pp67, 277; 1872, (I), p1. Reprinted as a text-book, 1872.

17 Lilian Gilchrist Thompson, loc cit p119.

18 R W Burnie, loc cit pp193, 294.

19 ibid, pp291, 292.

20 Lilian Gilchrist Thompson, loc cit p254.

21 ibid, p288.

22 H Bessemer, 'Autobiography', Engineering, 1905.

23 C Goodeve, 'Steelmaking Since Bessemer', J Iron and Steel Inst, Oct. 1956, p113.

24 H W Carr and W Taplin, loc cit p31.

25 W Larke, J Iron and Steel Inst 1936, p 96p (Discussion to ref 12).

26 A complete list of Thomas' contributions to 'Iron' are given in R W Burnie, loc cit, pp39,40.

27 Iron Age, 31st March, 1881.

28 J Mitchell, 'Sidney Gilchrist Thomas – A Commemorative Lecture', J Iron and Steel Inst, May 1950, p1.

29 W E Gladstone, 'A Rare Young Man', Youth's Magazine, (Boston, Mass). August 4th 1892.

30 R W Burnie, loc cit p17.

31 Andrew Carnegie, 'An American Four-in-Hand in Britain', Doubleday Doran, New York, 1933, pp83–87.

32 Lilian Gilchrist Thompson, loc cit p173.

33 ibid, pp293,294.

34 R W Burnie, loc cit p22.

35 ibid, p313.

The setting of the stage for Sydney Gilchrist Thomas

The British Steel Trade 1840 – 1880

K C Barraclough

The quarter century prior to Gilchrist Thomas' announcement of his solution to the phosphorus problem – 'the steelmaker's bane', according to H M Howe – at the Paris meeting of the Iron and Steel Institute in September 1878 saw a complete revolution in the iron and steel trade in this and other countries. Such was the confusion, indeed, that the American Institute of Mining Engineers thought fit to stage an international meeting in 1876 to set up an agreed table of definitions of the various grades of iron and steel; moreover, at that meeting, such authorities as Professor Holley, Lowthian Bell, Monsieur Greiner, Professor Tunner and Richard Akerman all failed to agree. A century later we may well wonder what all the fuss was about. The problem was, in reality, that prior to the Bessemer paper at the historic Cheltenham meeting of the British Association in 1856 the definition of iron and steel was quite simple. On quenching from a bright red heat into water, steel would harden; iron would not. The explanation of this state of affairs was quite straightforward. Wrought iron, the product of the puddling furnace, was essentially carbon-free and thus could not harden on quenching. Steel, on the other hand, was intentionally carburised wrought iron – subsequently rolled, forged or, alternatively, remelted in crucibles to produce ingots of cast steel. As such, it generally contained between 0.5% and 1.5% of carbon and all steel, therefore, would significantly harden on quenching. It is important to note that the production of material with 0.2% or 0.3% carbon was virtually unknown.

By 1878, however, about a million tons of 'Steel' a year were being made in Britain, mainly by the Bessemer process but also in the Open Hearth furnace and, as far as can be ascertained, the bulk of this fitted into the gap which previously existed between iron and steel. Such 'mild steel', as it came to be called, was in reality an extension of the wrought iron trade – it was largely used for engineering purposes, above all for railway rails, and also in part as a replacement for cast iron. The steel for cutlery, edge tools and ordnance was still being produced by the older 'Sheffield' methods, via the cementation and crucible furnaces; indeed, ingots of up to 25 tons were fairly regularly produced in Sheffield in the ten year period from 1868 onwards by pouring the contents of several hundred crucibles through a tundish into a single mould. The production of such an ingot for the forging of a gun tube for Woolwich Arsenal at Firth's works is described in 1874;[2] in this case 584 crucibles were used. This was the period, then, in which wrought iron began to be superseded by mild steel and also in which the differentiation between 'bulk steel' and 'special steel' arose. The true appreciation of the situation is complicated by a total rise in demand over the period and it is therefore appropriate to give some consideration to all three component groups.

In the first place, the best estimate for the production of wrought iron around 1855 seems to be about 1.3 to 1.5 million tons in Great Britain. The increasing demand, despite the inroads made by the new 'mild steel', brought about a doubling of the number of puddling furnaces between 1855 and 1875 and in the boom years of 1873 and 1882 it must be assumed that something over 3 million tons must have been made, although in 1877 a figure of only 1.8 million tons seems to be appropriate.[3] This is by far the bulk of ferrous material going into various engineering applications and it is worth noting that more wrought iron than total steel was made until as late as 1887.

Against this backbround, the amount of steel produced by the old traditional 'Sheffield' methods seems puny. As it happens, there are two assessments of total European steel production available within 15 years prior to the invention of the Bessemer process and they are worth a little study. Le Play, in his report of 1843,[4] provided the following summary of annual production:

Country	Natural Steel	Cementation Steel	Total
	tons	tons	tons
Great Britain	Nil	20200	20200
Austria	12600	Nil	12600
Germany	7000	100	7100
France	3320	3710	7030
Russia	520	2640	3160
Norway and Sweden	1970	8900	2860
Spain	200	100	300
Italy	100	100	200
TOTAL	25710	27740	53450

Natural steel was the continental material made direct from cast iron by refining out the bulk of the carbon but still leaving sufficient behind to give the required hardening effect; typically this was the famous Carinthian or Styrian Steel. In the above survey, Le Play estimated that some 80 to 85% of the British production came from the Sheffield area and that just over 50% of this was remelted in crucibles, giving a cast steel output of about 8500 tons. He was, however, at pains to point out that the state of trade was depressed at the time of his investigation and that the 97 cementation furnaces and the 774 crucible melting holes then available in South Yorkshire were capable of producing almost as much again, had there been the demand.

Twelve years later, Charles Sanderson produced a similar survey.[5] This indicated that, whereas total 'world' production had increased by some 50% in the interim, British production had doubled. The production of Natural Steel on the Continent had fallen slightly, giving well over 100% increase in the production of cementation steel. The figures in detail are as follows:

Country	Natural Steel	Cementation Steel	Total
	tons	tons	tons
Great Britain	Nil	40000	40000
Austria	13037	Nil	13037
Germany	3619	1834	5453
France	4408	10456	14964
United States	Nil	10000	10000
TOTAL	**21064**	**62390**	**83454**

From 1855 to 1878 the role of the cementation furnace changed considerably. One of the major factors resulted from a change in policy in Sweden, whereby from 1854 the direct export of Swedish cast iron was permitted; previously only bar iron had been exported. Swedish iron, of course, had been the basis of the cementation process since the late seventeenth century and only material of comparable purity could be considered as suitable for the production of steel in Sheffield. The normal procedure was to carburise the Swedish bar iron – in reality wrought iron produced by charcoal refining of the Swedish cast iron – by packing it in charcoal and heating it out of contact from the air in the chests of the cementation furnace. The product, blister steel, was in the main then used as raw material for remelting in crucibles to produce cast steel or 'Huntsman steel'. With the availability of the cast iron as well as the bar iron, however, it became obvious that the carburisation of the bar iron could be accomplished more cheaply and conveniently by using an admixture of Swedish cast iron and Swedish bar iron in each crucible. The use of the cementation furnace hereafter tended to decline, as is evidenced by the construction of some 384 double crucible holes at the new River Don Works of Naylor, Vickers and Company in 1863 without any provision being made for the production of blister steel on the site. Estimates of production in the Sheffield area in 1862 are given by Hunter[6] as 78270 tons of cementation steel of which sufficient was remelted in crucibles to produce 51616 tons of saleable metal; there were at that time 205 cementation furnaces and 2437 melting holes. Whilst no further estimates are to be found in the literature, it can be argued that these methods reached a peak, probably of the order of 120,000 to 130,000 tons, in 1873 and that, with the onset of the 'great depression' the figure had fallen to something around 60,000 to 80,000 annual tons by 1878.[7] It should be realised that this steel was relatively expensive – so much so that the process of 'steeling' or welding a steel edge to a backing of wrought iron was common practice in the making of edge tools so as to economise in the amount of steel used. Shear steel or the alternative cast steel, in forged bar form, would cost £60 a ton or more when wrought iron was selling at £10 to £15 per ton.

There was thus a growing consumption of both steel and iron and it was clear that if a stronger material than wrought iron could be produced at a price not markedly higher than the softer material there was a ready market for it. It was this thought that motivated a great amount of investigatory work in the 1850's and 1860's; the increased tempo can be judged by a survey of the patent literature of the period.

The earliest success in this field was in the production of puddled steel.[8] Since cast iron contains about 4% carbon and this all has to be burned out in the puddling furnace to produce wrought iron, if the process can be halted part way so as to leave from 0.3% to 1.0% carbon in the metal bloom taken to the shingling hammer, it follows that the resulting metal would have most of the characteristics of steel. The problem was in the control of the oxidation process, a problem that the Austrian makers of Natural Steel had learned to live with only by a sorting out process of the final material. The production of puddled steel was eventually worked out in Germany in the 1840's and in October 1851 the German process was demonstrated in the Low Moor Ironworks.[9] Low Moor took up the process as did the Mersey Iron and Steel Company; puddled steel was produced in quantity in the Loire district of France and also by Krupp in Germany. Of major interest, however, is the fact that Sheffield steelmakers entered the puddled steel business between 1857 and 1863; John Brown installed 72 furnaces at Atlas Works, Charles Cammell built 60 furnaces at Cyclops Works and Thomas Firth opened a new site at Whittington with 18 furnaces which were the source of 'the famous Firth puddled steel'.[10] This would also seem to tie in with the import of Swedish cast iron, from which John Brown is supposed to have produced high carbon melting base for crucible furnaces – this in effect would have been puddled steel. In this context a comment that cast steel made from puddled steel was more malleable than the generality of English iron converted into steel, coupled with a remark that the Low Moor puddled steel had not come much into use due to the high price put upon it, comes from T E Vickers of Naylor, Vickers and Company in 1858. There are no records of the amount of puddled steel produced but that this was substantial is underlined by a statement by Dr Percy in 1864 that 'puddled steel is now an article of great commercial importance'.[11]

It was against this background that Bessemer read his famous paper in Cheltenham in 1856. Ironmakers from all over the country and from Western Europe flocked to take out licences from him, for his process promised to provide the material which was in demand; moreover the costs would be such that it could be sold at a reasonable price and thus increase the demand. There followed a very traumatic period for Bessemer in which one licensee after another complained that the product was unusable and worthless. In part, this was due to over-oxidation of the metal. This problem was solved for Bessemer by Mushet on the one hand and by Goransson on the other; the former added manganese to the metal after the blow to correct the over-oxidation whilst the latter, operating at Edsken in Sweden on a high manganese pig iron, stopped the blow with a residual manganese content in the metal, thus obviating the over-oxidation. Bessemer meanwhile had decided to set up his own works in Sheffield, the heart-land of the British steel industry, and it is interesting to note that he purchased quantities of the high manganese pig iron, refined this in his converter, granulated the blown metal by pouring it into water, and finally remelted it in crucibles to produce cast steel in the normal manner. Before long, however, he had mastered the deoxidation technique and was producing ingots direct from the converter which rolled to billet in a satisfactory manner. Meanwhile, confidence in the Bessemer process had virtually gone; one French report of 1859 went so far as to state that the process had, for good reason, now been abandoned.

Bessemer was, however, not at the end of his troubles. The Swedish iron, like the Blaenavon pig which he had fortuitously used in his St Pancras experiments, was low in phosphorus. It must be reiterated that the use of low phosphorus iron for conversion into steel had become standard practice well before the end of the seventeenth century; Dannemore iron was accepted as the only really suitable material for the cementation process. It could, indeed, be argued that the success of Sir Basil Brooke in developing the cementation process in the 1620's after the failure of the original British patentees, Ellyott and Meysey, was due in large part to the nature of the iron which he would use in the Forest of Dean, which would be of the same character as that from Blaenavon.

The phosphorus problem is a complicated one. As far as wrought iron is concerned, phosphorus has little detrimental effect. As the carbon content of the metal rises, however, the embrittling effect of phosphorus makes itself felt, first at ambient temperatures, making the metal 'cold short', and then, with sufficient carbon and phosphorus, hot working problems can be met. Differences of opinion have existed down the years as to the permissible amount of this troublesome element; with steels with 1% carbon, however, the Sheffield trade has found 0.1% phosphorus is inadmissible and the bulk of the crucible steel contained less than 0.03%.

Steels with around 0.3 to 0.4% carbon seem to have been made fairly regularly, however, with up to 0.1% phosphorus without any serious shortcomings. Apart from the Forest of Dean ore, which is a haematite, the only other native source of low phosphorus ore is the Furness District of Lancashire. All other British ores are phosphoric, giving pig irons with up to 2% of phosphorus on smelting in the blast furnace. Bessemer took the obvious course of trying a pig iron smelted from the Cumberland ore; much to his disappointment, he found his product was still high in phosphorus. His investigations showed him that this was due to the use of Staffordshire puddling cinder, a cheap source of iron units, in the Cumberland blast furnace charge. On omitting this contaminated material a pig iron was obtained which gave satisfactory results.

It will be worth considering the difference between the refining of pig iron in the Bessemer converter and in the puddling furnace at this stage since both have the function of removing the carbon. In steelmakers' language, the Bessemer converter in its original form had an 'acid' lining, made from firebrick, silica brick and fused sand. The slag produced in the process was high in silica and was also 'acid' in character. The oxide of phosphorus is acid in character; any phosphorus oxidised in the acid surroundings cannot find any basic oxide to combine with it and therefore it hangs around, with a fair chance of being reduced back to phosphorus again by the metallic iron present. Under these conditions no positive removal of phosphorus can be achieved. In the puddling furnace, however, whilst the slag contains some silica, there is more than sufficient iron oxide present in the slag and in the lining to hold this fast as an iron silicate and the free iron oxide has a capacity for absorbing the phosphorus oxide and a positive removal of phosphorus can occur under these conditions; the puddling cinder, indeed, contained up to 6%, or in extreme cases 8%, of phosphorus oxide – which explains its contaminating effect in the Cumberland blast furnaces – whilst the phosphorus in the metal might be reduced from around 2% to about 0.2%. Puddled steel made using selected pig irons with lower phosphorus contents could be produced with acceptable phosphorus levels; George Parry of Ebbw Vale quotes a puddled steel with 0.5% carbon and 0.096% phosphorus produced by puddling an iron containing 0.426% phosphorus.[12] Parry, indeed, suggested a very reasonable solution to the immediate problem would be to remelt wrought iron scrap in the cupola, cast into slabs and repuddle it to remove still further phosphorus.[13]

The use of low phosphorus ore in the blast furnace was, of course, an obvious way of avoiding the phosphorus problem and this gave a big incentive to the mining of the Furness ore, and, indeed, to the setting up of further blast furnaces and of Bessemer converters in Barrow and West Cumberland. Such was the growth in this area that, whereas in 1857 only 50,000 tons of ore had been smelted locally and 600,000 tons had been exported, some 2½ million tons of local ore was smelted, supplemented to some extent by imports of Spanish haematite ore, in 1875. At this time the Barrow Haematite was the largest steelmaking plant in Britain – and perhaps in the world – with 18 Bessemer converters fed by 13 blast furnaces. At their peak Barrow and West Cumberland produced one sixth of the total British steel output; the meteoric rise in importance of this area was, of course, a direct result of the Bessemer invention. Its fall, almost as meteoric, was brought about by the Gilchrist Thomas invention, which opened up the vast reserves on a world wide scale of the phosphoric ores for steel production.

Methods of eliminating phosphorus were suggested in plenty and he patent literature abounds with them. Many of them were theoretcially impracticable being the application of all sorts of 'physic'. The remainder failed because of attack on the existing furnace linings. It was appreciated that a basic slag was essential quite early on in the saga; Gruner as early as 1857 had pointed out that a slag with less than 40% silica, and preferably less than 30%, was essential if the phosphorus oxide was to be retained and that a furnace lining rich in basic oxides would be necessary. William Siemens, whose Open Hearth procedure was becoming a rival to Bessemer's process, normally with a siliceous lining, tried the use of bauxite as a refractory to contain a basic slag but the lining failed because of the slag attack. Gruner returned to the problem in 1867 and suggested the use of dolomite as a possible lining material but was unable to make any progress.

The real pioneer work on a basic lining was in the event put on one side by one of those quirks of fate. George Snelus in 1870 was working in South Wales and came to the conclusion that a hard burned lime might just be practicable as a furnace lining; it worked on a laboratory scale. Further work suggested that magnesian limestone was superior to a straight calcium limestone and in 1872 he took out a patent for a hard burned magnesian limestone with a small amount of iron oxide as flux. He then changed his employment and went to West Cumberland; whilst he carried on his experiments in a rather desultory fashion in his new surroundings, it was hardly proper of him to try to convince the world outside that the haematite ores were not really essential for steel production and that phosphorus could be removed if suitable precautions were observed. He did reveal to the world in 1879, after the publication of the Gilchrist Thomas paper to the Iron and Steel Institute, that he had carried out successful experiments some years before, albeit on a small scale.[14] His paper is rather wistful:

> " *"Following these conclusions I made several blows in a small 2 cwt converter soon after I went to the West Cumberland Works. The results of these experiments I have shown to many private friends and I now have pleasure to lay the details before the Iron and Steel Institute . . .*
> *I have pleasure to place before the meeting what I believe to be the first sample of Bessemer steel made entirely from Cleveland ore by one operation in which the phosphorus has been reduced to a mere trace. A portion has been forged into a chisel, while a rough portion of the same still has part of the lime lining attached to it. With the samples I have placed the original wrapper bearing the date when the sample was made and also my note book with the original entries of the details of the analysis."*

It was thus entirely appropriate – and for that matter entirely typical of the attitude of Gilchrist Thomas – that George Snelus should eventually be brought into the partnership for the administration of the foreign patents covering the basic process.

Meanwhile the problem of phosphorus in steel was exercising the minds of others, among them Krupp in Germany and Lowthian Bell in this country. Both achived a very limited success by using slags high in iron oxide. Such was Bell's stature in the metallurgical world that his repeated failure to find a solution tended to the opinion that the problem was insoluble. He presented two papers to the Iron and Steel Institute in 1877 on the reactions in the puddling furnace and the Bessemer converter; in the discussion of the third paper,[15] given at the Spring meeting in 1878 and obviously showing that his researches were foundering, Professor Williamson enquired whether it had occurred to Mr Bell that some benefit might be gained by replacing some of the iron oxide in the slag by a non-reducible basic oxide, such as lime or some other base of comparatively little value. George Snelus informed the meeting that he had taken out a patent for using lime as a lining for steel-making and that the patent was still valid. The most interesting contribution to the discussion came from one of the youngest members present, a Mr Sidney Thomas, who stated that he had succeeded in effecting the almost complete removal of phosphorus in the Bessemer process. He believed the pratical difficulties in the way had been overcome and that Cleveland pig might be made into good steel without any intermediate process. Mr Bell's reply to the discussion included an acknowledgement of Professor Williamson's comments, indicating that he had actually tried the addition of lime but his tests were not yet in a sufficiently advanced state to enable him to deal with the matter at present. He did not comment on Mr Snelus' contribution. A further comment is worth quoting verbatim, however:

> *"With regard to what Mr Sidney Thomas hoped to do with the Bessemer converter, he was so much interested in freeing iron, and particularly Cleveland iron, from phosphorus, that he should hail as a public benefactor any gentleman who would come forward and do the work more perfectly and more economically than he had been able to effect this object himself."*

This concludes the introduction and sets the scene for a discussion of the work carried out by the above mentioned Mr Sidney Thomas. Anyone reading the full discussion of Lowthian Bell's paper of 1878, however, will certainly never fail to note the contribution of a Mr Francis Fox who, noting the statement in Mr Bell's paper that nearly five sixths of the metal obtained from English ores contained so much phosphorus as to render it unfit for the manufacture of steel, said there could be no more conclusive proof of the extreme importance of the subject being thoroughly well considered. He went on to propose an Institute committee for the purpose of studying the properties of iron and steel. But it is final paragraph which remains in the mind with its prophetic utterance:

> *"There was another point which he ventured to call attention to, but being a civil engineer, and not a chemist, he only threw it out as a suggestion. Might it not be perfectly within the bounds of possibility that the phosphorus, instead of being treated as of no value at all, might be regarded as a residual product? Only a few years ago the residual products of gas were thrown away as useless, whereas he believed that at the present day they were considered of sufficient value to cover the whole cost of manufacturing the gas. Might not some cheap and easy method be devised whereby, instead of the cost of the elimination of the phosphorus being thrown upon the iron, the phosphorus might be made to bear a portion of its own cost? It has been stated at Newcastle that as much as 16% of phosphorus was found in the cinder and might not that in some way be used with the ammonical products of the gasworks as a manure?*

REFERENCES

1 H M Howe: 'The Metallurgy of Steel', New York, 1891, p.54.

2 Sheffield and Rotherham Independent, 28th April, 1874.

3 J C Carr and W Taplin: 'History of the British Steel Industry', Oxford 1962, p.95, quoting J S Jeans.

4 F le Play: 'Rapport sur la Fabrication de l'Acier en Yorkshire, ", Annales des Mines, Tome III, 4me Serie, 1843, p.692. A translation appears in Historical Metallurgy Volume 8, Part 1, 1974

5 C Sanderson: 'On the Manufacture of Steel . . .", Journal of the Royal Society of Arts, Vol.3, 1854-5, pp. 450-459.

6 J Hunter: 'The History and Topography of the Parish of Sheffield in the County of York', edited Gatty, 1869, p.216.

7 K C Barraclough: 'The Production of Steel in Britain by the Cementation and Crucible Processes', Historical Metallurgy Volume 8, Part 2, 1974, pp.103-111.

8 This topic is discussed at length in the author's paper 'Puddled Steel: A Forgotten Chapter in the History of Steelmaking', JISI, October 1971, pp.785-789 and December 1971, pp.952-957.

9 H Fehland: 'Geschichtliches über die Puddelstahl Fabrikation', Stahl und Eisen, 1886, p.228.

10 A C Marshall and H Newbould: 'The History of Firth's, 1842-1918', published privately, 1924, p.22.

11 J Percy: 'Metallurgy – Iron and Steel', 1864, p.791.

12 G Parry: 'On Puddled Steel', Proceedings South Wales Institute of Engineers, Vol. iii, 1862-3, pp.74-81.

13 G Parry: British Patent 2900, AD 1861.

14 G J Snelus: 'On the Removal of Phosphorus and Sulphur during the Bessemer and Siemens-Martin Processes of Steel Manufacture', JISI, 1879, Part I, pp.135-143.

15 I Lowthian Bell: 'On the Separation of Phosphorus from Pig Iron', JISI, 1878, Part I, pp.17-34; Discussion pp.34-47.

Cleveland and the Basic Process of Steelmaking

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Summary
Following experimental work done in South Wales, it was in Cleveland that the conditions necessary for successful removal of phosphorus from liquid iron were firmly established, and the first commercial steel was made from British ore high in phosphorus. The 'basic' method of steelmaking was quickly adopted on the Continent of Europe, and more slowly within Britain: today a high proportion of world steel output depends upon the techniques discovered just a century ago.

The situation that existed in the Cleveland iron-and-steel industry a century ago is noted, and the problems that had to be overcome in order to make satisfactory 'basic' steel from Cleveland ore are enumerated. A brief summary is given of the development of 'basic' conditions of steelmaking– in other kinds of vessel as well as by converter – during the one-hundred years that have followed. Graphs show the growth of British steel output in the period and the increasing proportion obtained by basic processes. Biographical sketches outline the important contributions made in the years around 1880 by the 9 people most closely concerned in Britain with the establishment of commercial basic steelmaking.

Cleveland, and the Middlesbrough Industry in 1878

From antiquity the Cleveland district of Yorkshire has had distinct identity, referring to the area of upland lying in the extreme northeast of the county, inland from Whitby and bounded on the north by the River Tees. Under reorganisation in the 1970s a new county – Cleveland – was formed: this includes those northern portions of the old Cleveland district adjacent to the Tees, together with some districts on the northern bank of the river formerly in Co Durham – Stockton and Hartlepool. Chiefly because of the inclusion of Hartlepool, Cleveland County is larger than the 'Teesside' from which it has grown, but it retains as its focus the lower reaches of the River Tees.

Middlesbrough, situated on the southern bank of the River Tees about 15 km from the mouth, owed its earliest phase of development to the shipment of Durham coal in the 1830s. It was twenty years later, in the 1850s, that the second and more-important industrial phase began when ironworks were established on both banks of the river, drawing upon the deposits of ironstone newly-found in the nearby Cleveland Hills together with coal from South-West Durham. The third quarter of the 19th century was a period of great progress and expansion in the area around Middlesbrough, and the men who promoted the vigorous iron-making developments were then in their prime. The new iron industry was planted on the low-lying land of the river's banks which afforded transport facilities by both rail and water. The two largest works were those of the Bell Brothers (on the north bank of the river, at Port Clarence) and of Henry Bolckow and John Vaughan (on the south bank, in Middlesbrough itself).

By the beginning of the fourth quarter of the century, however, a good deal of the first flush of Middlesbrough's iron prosperity had gone, to be replaced by financial failures caused by the adverse trading conditions that then prevailed, and the fact that, in the 1870s, steel was starting to replace puddled iron in world markets. To try to keep up with the changed conditions, Bolckow, Vaughan & Co set about the building of new works on the south bank of the river between Middlesbrough and Redcar – the Cleveland Works, situated within the parish of Eston. These works comprised three blastfurnaces to make iron from phosphorus-free ores imported from Spain, and 4 Bessemer converters, with all necessary ancillary equipment, to convert the iron to steel and then to shape it into rails. The first output of steel from the works came in 1877. Meanwhile all the other works in the district, including the older plant of Bolckow, Vaughan in Middlesbrough, continued to make such quantities of iron as could be sold; for this the raw material was local Cleveland ironstone, abundantly available, but high in phosphorus content and for this reason impossible to process into steel. Bolckow, Vaughan's possessed the mining rights to very-large tonnages of phosphoric ironstone.

Exactly a century ago, in 1878, there was thus in Cleveland considerable commercial incentive to adopt any measures that would permit production from local ironstone of metal that could compete in the changed market conditions.

One way in which a solution had been sought was the mechanised puddling furnace, and no fewer than 18 of these, or 40 per cent of the British total, were installed in the district during the 1870s. Another technique was under development by the internationally-known ironmaster Isaac Lowthian Bell: this involved 'washing' the phosphorus out of the liquid metal by contact with an iron-rich fluid slag, but by 1878 it had not reached a stage of commercial practicality.

The problem of phosphorus removal from iron was not confined to Cleveland. On the Continent of Europe too, as well as in other parts of Britain, investigations were being actively pursued. In Germany, Krupp, using a technique similar to that of Bell, was claiming considerable success. Assertions and rumours on the subject of phosphorus in iron and steel were widespread and helped to feed the columns of the technical press.

In these circumstances it is not surprising that E Windsor Richards, the general works manager for Bolckow, Vaughan & Co, should consider it worth his while to travel to Blaenavon in South Wales on 2 October 1878, to investigate what Sidney Thomas and Percy Gilchrist, with the help and encouragement of E P Martin, had already achieved.

The Cleveland Developments, 1878–79

When Thomas and Gilchrist moved from South Wales to Cleveland in the autumn of 1878 they brought with them the experimentally-proved knowledge that phosphorus could be removed from liquid iron by blowing the melt with air in presence of sufficient lime. They had also established that a coverting-vessel lining composed of hard-burned impure magnesian-limestone blocks would hold together long enough for a small-scale working at the exceedingly-high temperatures involved (more than 1600°C), although due to the unavoidable joints it was not sufficiently permanent to enable 'blows' of more than one or two tonnes to be successfully treated.

It was therefore natural that a considerable part of the feverish experimental work done in Cleveland in the winter months of 1878-79 should be focussed upon the problem of how to obtain a more-durable lining for the converting vessel. By the early part of March 1879 the answer had been found – hot boiled tar mixed with the hard-burned dolomitic lime – but other serious difficulties then became apparent. The most immediate of these was the depressing fact that most of the phosphorus did not leave the metal in the conditions used: to J E Stead is given the credit for urging that an 'overblow' or 'afterblow' was needed in order to eliminate the troublesome element from the metal. (Detailed chemical analyses of samples taken during the course of a blow were available in May 1879 – Table 1. A few months later Windsor Richards showed graphically the chemical changes that occur during the converting process – Figure 1). This breakthrough achieved by the prolongation of blowing enabled a demonstration of two operations – both apparently successful – to be given to invited guests, mostly local businessmen, on Friday 4 April 1879. It was in connexion with this event that Windsor Richards later wrote the passage so widely quoted:[2]

> "The news of this success spread rapidly far and wide, and Middlesbrough was soon besieged by the combined forces of Belgium, France, Prussia, Austria, and America."

More demonstrations were given during the following month, but further serious problems now came to the fore, and it was several years before regular production of useable metal from Cleveland phosphoric ore became commercially assured.

A Summary of the Problems

1. Providing a basic lining sufficiently durable to give commercial viability. Hot boiled tar was found to be the key to successful binding, but there were also problems involved with the firing of the dolomite into satisfactory bricks.

2. Achieving adequate removal of phosphorus from the metal during the course of steelmaking. The continuation of blowing for a minute or two after the carbon had been oxidised from the metal (ie. the 'afterblow') was found to be essential. Reversion of the phosphorus then had to be prevented by suitable techniques for slag removal and de-oxidation.

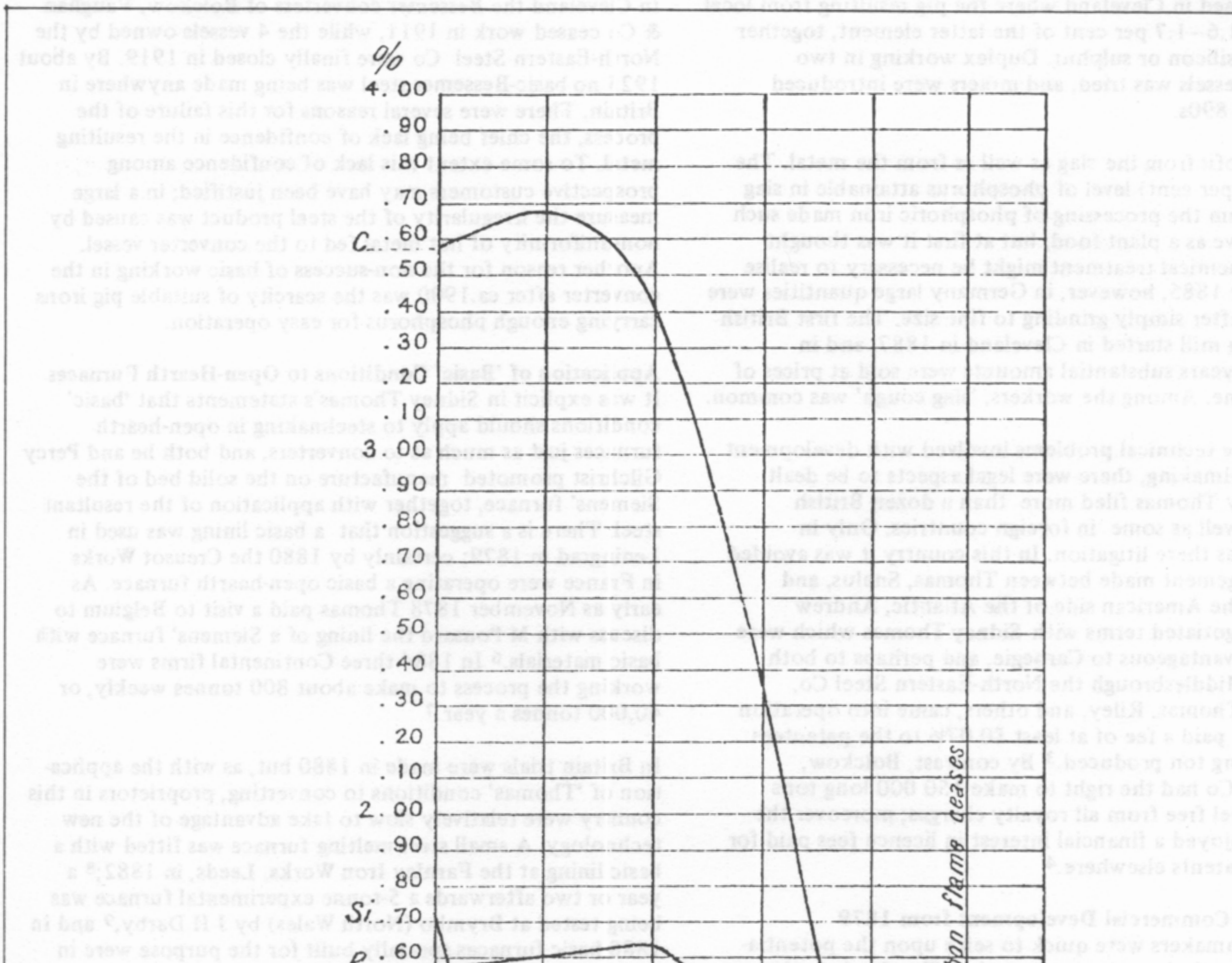
3. Dealing with the large bulk of slag involved and, in the converter, with the formation of crusts in the cooler nose section. As far as steelmaking in the converter was concerned, a symmetrical shape was adopted for the vessel (Figure 2) with a firebrick lining to the nose, while the arrangement of the vessels in the shop needed to allow for easy access. In open-hearth steelmaking, modifications were made to the positions of the regenerator chambers relative to the hearth to minimise the amount of lime and slag blown in, and the advent of the tilting furnace, ca. 1900, was of great advantage.

4. Providing, as feed to the process, metal of suitable composition for treatment. To some extent this problem is a continuing one, and it involves ironmaking and the composition of raw material used. It is more acute in converting processes than in the open-hearth (or electric-arc) furnace. Early basic-Bessemer steelmakers needed iron containing low silicon and high (2 per cent) phosphorus, a combination not

TABLE 1

Earliest surviving record of blow, 3 May 1879)[1]
(Figures in percentages)

metal samples	silicon	graphite	combined carbon	phosphorus	time	
					mins.	secs.
pig iron	2.89	3.36	0.06	1.52	–	–
1	2.21	2.64	0.80	1.51	3	0
2	1.43	0.06	2.55	1.51	6	0
3	0.78	trace	2.50	–	9	0
4	bad sample					
5	0.13	nil	0.53	1.36	12	0
6	0.10	nil	nil	1.01	15	0
7	trace	nil	nil	0.77	17	30
8	nil	nil	nil	0.41	18	30
9	nil	nil	nil	0.12	19	30
10	nil	nil	nil	0.10	20	30
steel	nil	nil	nil	0.18	21	10
				(manganese 0.15)		



Slag	3 Min.	6	9	12	14½	16½	16 Min 35 Sec.
Silica	32.60	42.60	36.00	35.60	33.00	15.60	15.60 %
Phosp Acid	0.60	0.15	1.60	2.61	5.66	15.06	16.03 %
Iron	5.65	2.00	4.60	4.80	6.15	10.45	11.35 %

Figure 1 Chemical changes occurring during the converting process (JISI, 1879)

easily obtained in Cleveland where the pig resulting from local ore carried 1.6–1.7 per cent of the latter element, together with either silicon or sulphur. Duplex working in two successive vessels was tried, and mixers were introduced during the 1890s.

5 Realising profit from the slag as well as from the metal. The high (ca.15 per cent) level of phosphorus attainable in slag resulting from the processing of phosphoric iron made such slag attractive as a plant food, but at first it was thought extensive chemical treatment might be necessary to realise its value. By 1885, however, in Germany large quantities were being used after simply grinding to fine size. The first British slag-grinding mill started in Cleveland in 1887, and in subsequent years substantial amounts were sold at prices of £1-£2 a tonne. Among the workers, 'slag cough' was common.

Besides these technical problems involved with development of basic steelmaking, there were legal aspects to be dealt with. Sidney Thomas filed more than a dozen British patents, as well as some in foreign countries. Only in Germany was there litigation. In this country it was avoided by an arrangement made between Thomas, Snelus, and Riley. For the American side of the Atlantic, Andrew Carnegie negotiated terms with Sidney Thomas which were certainly advantageous to Carnegie, and perhaps to both parties. In Middlesbrough the North-Eastern Steel Co, created by Thomas, Riley, and others, came into operation in 1883 and paid a fee of at least £0.07½ to the patentees for every long ton produced.[3] By contrast, Bolckow, Vaughan & Co had the right to make 150 000 long tons a year of steel free from all royalty charges; moreover the company enjoyed a financial interest in licence fees paid for use of the patents elsewhere.[4]

World-Wide Commercial Development from 1879

German ironmakers were quick to seize upon the potentialities of the technique demonstrated in Cleveland, so that on 22 September 1879 the first rails of 'basic' or 'Thomas' steel were rolled at Hoerde from metal made there. By the year's end at least ten Continental proprietors were in process of adopting the 'basic' converters, and shortly afterwards reliable and economic steel was being regularly produced. In Britain at the end of 1879 there were more than 100 small acid-lined Bessemer converters in existence at nearly 30 works. Following the Cleveland trials and the great publicity of spring 1879, the new method for dealing with phosphoric irons was taken up in Sheffield (by Brown, Bayley, & Dixon) and in Staffordshire (on a small-scale trial basis at Wednesbury in the works of the Patent Shaft and Axletree Co, and then by the Staffordshire Iron Co of Bilston). Within Cleveland, a fresh installation of 6 'basic' converters was laid down as an addition to Bolckow, Vaughan's works at Eston Junction, and in 1883 a completely new plant built by the North-Eastern Steel Co began operation with Sidney Thomas amongst the directors and Arthur Cooper as manager. In Scotland, two works started ca.1885 with a total of 7 converters. By 1890 there were thus installed in Britain some 7 basic-converting plants, equipped with more than 20 vessels between them.

Abroad, the numbers were substantially higher. By 1910, while British basic-Bessemer output of ingots amounted to 650 000 tonnes, the corresponding figure in Germany had reached 8 150 000 tonnes – or roughly 12 times as much – and in the same year France contributed 2 160 000 tonnes. In the USA, on the other hand, although the basic-Bessemer method was adopted during the 1880s, by 1900 it had been abandoned in favour of basic open-hearth furnaces. The proportions of steel made in basic-Bessemer converters by some major producing countries in the early years of the present century are summarised in Table 2.

In Cleveland the Bessemer converters of Bolckow, Vaughan & Co ceased work in 1911, while the 4 vessels owned by the North-Eastern Steel Co were finally closed in 1919. By about 1925 no basic-Bessemer steel was being made anywhere in Britain. There were several reasons for this failure of the process, the chief being lack of confidence in the resulting metal. To some extent this lack of confidence among prospective customers may have been justified; in a large measure the irregularity of the steel product was caused by non-uniformity of hot metal fed to the converter vessel. Another reason for the non-success of basic working in the converter after ca.1900 was the scarcity of suitable pig irons carrying enough phosphorus for easy operation.

Application of 'Basic' Conditions to Open-Hearth Furnaces

It was explicit in Sidney Thomas's statements that 'basic' conditions should apply to steelmaking in open-hearth furnaces just as much as to converters, and both he and Percy Gilchrist promoted manufacture on the solid bed of the Siemens' furnace, together with application of the resultant steel. There is a suggestion that a basic lining was used in Leningrad in 1879: certainly by 1880 the Creusot Works in France were operating a basic open-hearth furnace. As early as November 1878 Thomas paid a visit to Belgium to discuss with M Ponsard the lining of a Siemens' furnace with basic materials.[6] In 1884 three Continental firms were working the process to make about 800 tonnes weekly, or 40,000 tonnes a year.[7]

In Britain trials were made in 1880 but, as with the application of 'Thomas' conditions to converting, proprietors in this country were relatively slow to take advantage of the new technology. A small steel-melting furnace was fitted with a basic lining at the Farnley Iron Works, Leeds, in 1882;[8] a year or two afterwards a 5-tonne experimental furnace was being tested at Brymbo (North Wales) by J H Darby,[9] and in 1888 basic furnaces specially built for the purpose were in use in steelworks there and at Frodingham (Lincolnshire). In Cleveland the first significant output of steel obtained in basic-lined reverberatory furnaces came ca.1890 from Bell Brothers' Clarence Works, but the process was not continued; it was re-started there commercially in 1901, and in subsequent years the basic open-hearth furnaces at various works in Cleveland became substantial contributors to total British steel production. Between 1903 and 1910 several installations were made in the district of large (175-250 tonne) tilting furnaces in which the Talbot process of 'continuous' steelmaking was carried out. Such tilting furnaces were well suited to dealing with the large bulks of limey slag generated in basic working.

The proportion of British steel made under basic conditions has increased continuously from 1879 to the present day – see graph, Figure 3 – eg from about 10 per cent (in 1890) to more than 98 per cent (by 1970). For several reasons, in Britain the open-hearth furnace came to be preferred to the Bessemer converter, in contrast with the Continent of Europe where the proportion of steel made by converting remained comparatively high throughout the first half of the present century. The proportions of total steel output made by the basic open-hearth process in the three principal producing countries in the years 1900 and 1910 were as shown in Table 3.

The Last Half Century of Basic Steelmaking, 1928 Onwards

By 1928 in Britain the basic-Bessemer process had been completely discarded in favour of basic open-hearth furnaces. Then courageous attempts were made to re-introduce the converting process at two new plants – at Corby (1934) and Ebbw Vale (1938) – so that, throughout the 1940s and 1950s the combined annual output of basic-Bessemer steel

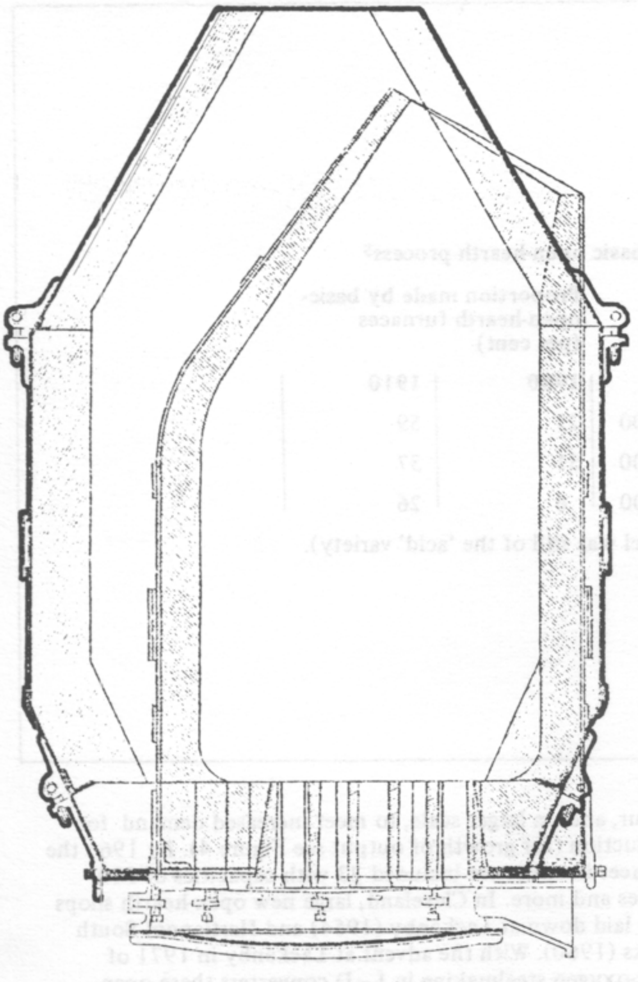


Figure 2 Symmetrical shape of 15-ton basic-lined converters built for Bolckow, Vaughan and Company's Cleveland Works shortly after 1880, compared with a conventional small vessel of the time. (Proc. Cleveland Instn. Engrs. 1880–81)

amounted to some ¾-million tonnes this was used for making pipes and soft sheets for tinplate. By comparison with the 8 basic converters at work in Britain, on the Continent around 1947 there existed more than 120 vessels.[10] Ten years later, this imbalance was just as marked (Table 4).

The problem of the hardening effect of the high nitrogen content of basic-Bessemer steels – say 0.016 per cent, or two to three times the level to be expected in metal from the open-hearth or electric-arc furnace – was tackled by a variety of means, both in the British plants and those abroad. Essentially, the quantity of air blown through the melt had to be restricted, especially at the end of the refining period when the steel was particularly susceptible to nitrogen pick-up. To substitute for some of the air used, steam, carbon dioxide, and oxygen were all applied commercially in efforts to produce low-nitrogen steels. At the Abbey Steelworks, Port Talbot, South Wales, shortly before 1960 a new Thomas converting plant came into operation: it used an oxygen-steam blast in place of air, and its product, suitable for deep-drawing, had a nitrogen content of below 0.03 per cent.

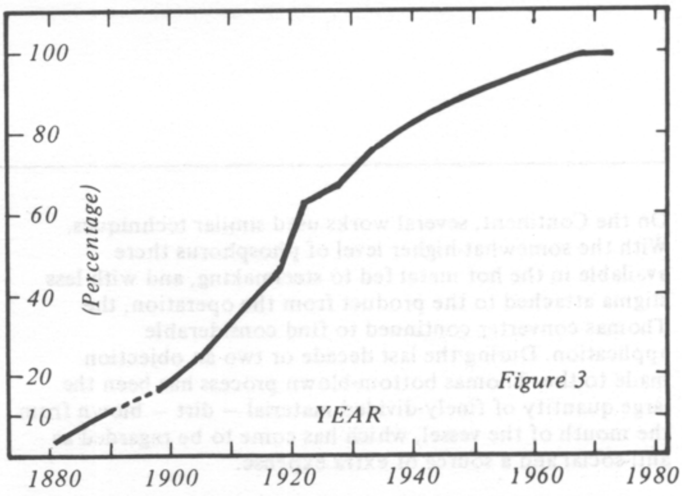


Figure 3

Proportion of British steel output made in contact with basic linings.

TABLE 2

Proportion of national steel output made in basic-Bessemer converters[5]

Country	Total output of ingots (tonnes – rounded)		Proportion made in basic-Bessemer converters (per cent)	
	1900	1910	1900	1910
Germany	6 610 000	13 520 000	64	60
Britain	4 980 000	6 100 000	10	11
France	1 590 000	3 410 000	na.	63
Austria-Hungary	1 164 000	2 170 000	21	14

(for Russia separate figures are not available)

TABLE 3

Proportion of national steel output made by basic open-hearth process[5]

Country	**Total output of ingots (tonnes – rounded)**		**Proportion made by basic-open-hearth furnaces (per cent)**	
	1900	**1910**	**1900**	**1910**
USA	10 240 000	26 320 000	25	59
Germany	6 610 000	13 520 000	31	37
Britain	4 980 000	6 100 000	6	26

(Note – in Britain at 1910, 63 per cent of steel was still of the 'acid' variety).

On the Continent, several works used similar techniques. With the somewhat-higher level of phosphorus there available in the hot metal fed to steelmaking, and with less stigma attached to the product from the operation, the Thomas converter continued to find considerable application. During the last decade or two an objection made to the Thomas bottom-blown process has been the large quantity of finely-divided material – dirt – blown from the mouth of the vessel, which has come to be regarded as anti-social and a source of extra expense.

The 1960s saw further changes: Richard Thomas & Baldwin's plant at Ebbw Vale closed in 1962, to be followed by Stewarts & Lloyd's basic converters at Corby in January 1966.[12] At Port Talbot the Steel Co of Wales' very-low-nitrogen (VLN) plant ceased work in 1968. This time the competition was not from open-hearth furnaces but from the modified scheme of converting that resulted in the top-blown oxygen processes: the first L–D plant in Britain was installed at Ebbw Vale in 1960, to be followed in 1962 by a plant at Richard Thomas & Baldwin's other works at Newport, Monmouthshire. In the same year (1962) an L–D converter came into production at Corby, and by 1965 that Midland works had installed a trio of 100-tonne vessels. It is no coincidence that the two companies which had successfully used basic-Bessemer converters throughout the 1950s should be the first in Britain to switch to top-blown vessels. The Port Talbot plant switched from VLN to two 300-tonne LDs. By 1969 no fewer than 29 top-blown converters had been installed at works in all parts of the country, and the basic open-hearth furnace had met its match. On the Continent, an alternative scheme adopted for some bottom-blown Thomas converters has been modification of the tuyere arrangement to admit cooling gas at the same time as oxygen, so giving rise to the OBM, or Q–BOP, method of steel converting.

In Britain, open-hearth steelmaking was the predominant method from ca.1890. In 1928 the open-hearth furnace reigned almost supreme (the exception being the acid-Bessemer plant of the Workington Iron & Steel Co in West Cumbria), and in the succeeding 40 years it continued to find favour, and on larger scale, to meet increased demand for production (for growth of output see Figure 4). By 1966 the furnaces in existence included 23 with capacities of 300 tonnes and more. In Cleveland, large new open-hearth shops were laid down at Lackenby (1954) and Hartlepool South Works (1960). With the advent at Lackenby in 1971 of basic-oxygen steelmaking in L–D converters these open-hearth installations, together with several older ones, became redundant. To a limited extent the basic electric-arc furnace for bulk steelmaking from scrap has been a contributory factor in the downfall of the open-hearth furnace from its dominant position.

At any rate in Britain, the proportion of steel now made in vessels with basic linings is almost total (Figure 3). World-wide, with all methods in use today for making steel from blast-furnace pig iron containing appreciable levels of phosphorus (ie more than 0.05 per cent), the fundamental principles of treatment remain as they were when worked out just a century ago. These principles are:

1 there must be abundant lime (CaO) present to react with the oxides of phosphorus formed in the oxidising conditions that prevail; and

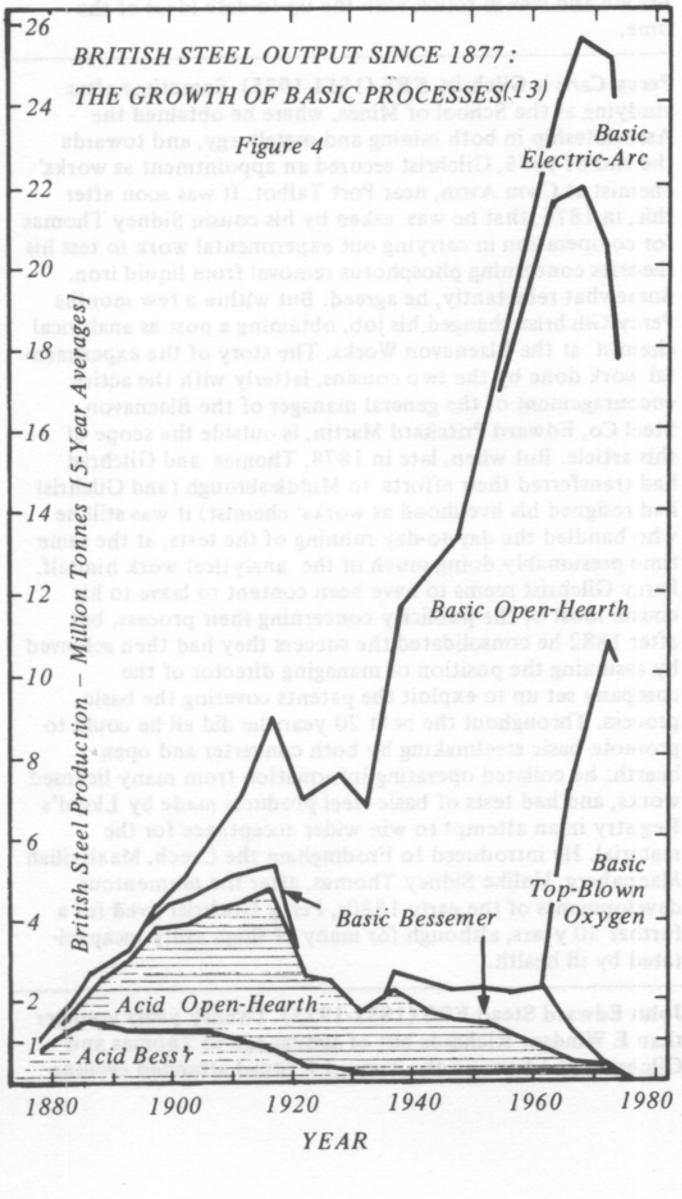
2 the lining of the vessel must be compatible and non-reactive with the basic, oxidising materials it contains, at temperatures in excess of 1600°C. (Tar-bonded hard-burned dolomite has to some extent given place to hard-burned magnesite for the purpose).

Sidney Thomas, Percy Gilchrist, and their collaborators stated these conditions and showed how they might in practice be successfully met. Without the ability to remove the troublesome element phosphorus from liquid blast-furnace iron, the world steel industry would have remained extremely limited in its development. Production of steel might then have been restricted to only about one-tenth of the levels achieved, and the impact of steel upon man's way of life in the 20th century would have been correspondingly small. As it is, in the present generation of steel-making processes, Thomas, Gilchrist, Windsor Richards and Stead would have no difficulty in recognising the fruits of their work in the years 1878–1880.

TABLE 4

Proportion of national steel output attributable to basic-Bessemer process, 1957[11]

Country	Proportion of output made by basic-Bessemer process
Belgium and Luxembourg	85 per cent
France	61
W Germany	43
Britain	less than 6



BRITISH STEEL OUTPUT SINCE 1877 : THE GROWTH OF BASIC PROCESSES(13)

Figure 4

The People Involved in Establishing Basic Steelmaking in Cleveland

In considering the development of the basic process, from the earliest ideas to established commercial success in Cleveland in 1883, there seem to be 9 people whose contributions to the technological achievement were outstanding. These men (arranged by descending age) are:

	in 1879 aged
Edward Williams	52
E Windsor Richards	47
Edward Riley	47
Edward Pritchard Martin	44
George J Snelus	41
Arthur Cooper	39
Sidney G Thomas	28
John E Stead	27
Percy C Gilchrist	27

Of the group, 6 played active parts in helping the industry to blossom in Cleveland, the contributions of another two – Edward Riley and George Snelus – being limited to making general advances in satisfactory lining materials. Important though it was, the influence of the remaining man, E P Martin, was confined to the work done in South Wales. Of the 9 men, three – the two eldest and E P Martin – were born in South Wales, and received their early works' training and experience there; for various periods three of the others were employed as chemists in ironworks in the Principality. No less than 4 of the 9 received technical instruction at the School of Mines in London. Fuller biographical notes are given in the paragraphs that follow.

Edward Williams (1826-1886) Born in Merthyr Tydfil, he began work with the Dowlais Iron Company in 1842 and, after the announcement in 1856 of the Bessemer process, became involved in experiments with it and with the rolling of the first steel rails from it.[14]

In 1864 Edward Williams left Dowlais for London and in the following year he travelled north to Cleveland on his appointment as general manager of Bolckow, Vaughan & Company, an organisation at that time newly formed from the previous successful and pioneering iron-making partnership of Henry Bolckow and John Vaughan. Williams remained as general manager of the Cleveland company for 10 years; during this time he was instrumental in carrying through considerable expansion in the businesses of coal mining, ironstone mining, ironmaking, refining, and shaping. While he was manager the company's foundations for bulk steelmaking were laid, and he was praised by the directors for his energetic and determined efforts on their behalf. Nonetheless, at the end of 1875 Edward Williams resigned from Bolckow, Vaughan's employment and established an ironworks in Middlesbrough on his own account. This was not his last contact with bulk steelmaking, however, for although remaining a Cleveland resident he designed and set up for the Crawshay Brothers the Bessemer steelworks at Cyfarthfa, South Wales. He was also president of the Iron and Steel Institute in 1879-80, occupying the chair at the important meeting of May 1879 when so much concerning the basic process was stated and discussed.

E Windsor Richards (1831-1921) Son of the general manager of the Rymney Ironworks, Windsor Richards served his apprenticeship with that company. In 1854 he moved to the Tredegar Ironworks, and in 1871 he was appointed general manager of the Ebbw Vale Works where he gained immediate first-hand experience of laying out a plant for Bessemer steel.[15] At the end of 1875, however, he migrated to the North East of England to become general manager of mining and metallurgical works for Bolckow, Vaughan & Co in place of Edward Williams, 5 years his senior. In Cleveland, Windsor

Richards found himself involved with the erection and commissioning of Bolckow, Vaughan's new Bessemer steelworks at Eston Junction (the Cleveland Works) together with blastfurnaces to supply the necessary low-phosphorus pig iron. The Cleveland Steelworks began production at the time that Sidney Thomas and Percy Gilchrist were actively experimenting in South Wales. Windsor Richards became acquainted with Thomas during the celebrated Paris meeting of the Iron and Steel Institute in the autmn of 1878; soon after return to Britain he travelled to Blaenavon with the company's consultant J E Stead to witness a demonstration of what Thomas and Gilchrist could offer. This was sufficiently impressive for Richards to invite the two young technologists to pursue their work in Middlesbrough. Once in the North East, it was Richards who provided the necessary logistic support and engineering backing; he took a large part in translating small-scale experiments accompanied by uneconomically-high lining consumption into commercially-successful steel-making operations on the scale of 5-15 tonnes at a time. Windsor Richards moved from Cleveland in 1888 to take up less-arduous duties as general manager of the Low Moor Ironworks. Nevertheless he retained a large measure of interest in Bolckow, Vaughan & Co's works as a director, and was for a period of some years the company's chairman.

Edward Riley (1831-1914) Received training at the School of Mines in London between 1850 and 1853 and was then appointed chemist of the Dowlais Ironworks where he stayed for 6 years. In subsequent years from his London consulting base he did much analytical work for Bessemer. In November 1878 he took out a patent (British no. 4780) for a furnace lining made of magnesian lime ground with oil, and this gave him a claim to share in proceeds from commercial working of the 'basic process'; in 1881 he was a leading promoter of the North-Eastern Steel Company, formed to make steel in Middlesbrough by the new process. Shortly afterwards he was associated with the South Staffordshire Steel Ingot Co Ltd, established to make basic steel at Bilston.[16]

George J Snelus FRS (1837-1906) A Londoner by birth, trained as a teacher of science, and a distinguished student at the School of Mines (1864-1867), Snelus joined the Dowlais Ironworks as chemist ca.1868.[17] There he carried out investigation into the nature of the gases evolved during the progress of a Bessemer blow, as well as into the conditions favouring removal of phosphorus during the refining of iron. It appears likely that, by 1873, Snelus had successfully removed phosphorus from Cleveland pigiron on a scale of 50-100 kg; but he encountered difficulty in repeating the process on a larger scale as for a 7-tonne converter he could not prepare a sufficiently-strong lining of hard-fired crushed limestone. Snelus protected at least a part of his discoveries by British patent (no.908 of 1872); very soon afterwards he was appointed manager of the Bessemer department of the West Cumberland Steelworks. In his new job he was fully occupied: moreover the various works in West Cumbria were experiencing favourable trading conditions because of their fortunate position close to sources of hematitic ore that was not only of high grade but also free from phosphorus. In these circumstances it is hardly surprising that nothing more was heard of George Snelus's experimental advances until Sidney Thomas announced his discovery in 1878. Snelus then secured a USA patent. With the combination of patents in the two countries he had a claim to a share of any profit that might arise from the 'basic' process promoted by Thomas and Gilchrist.

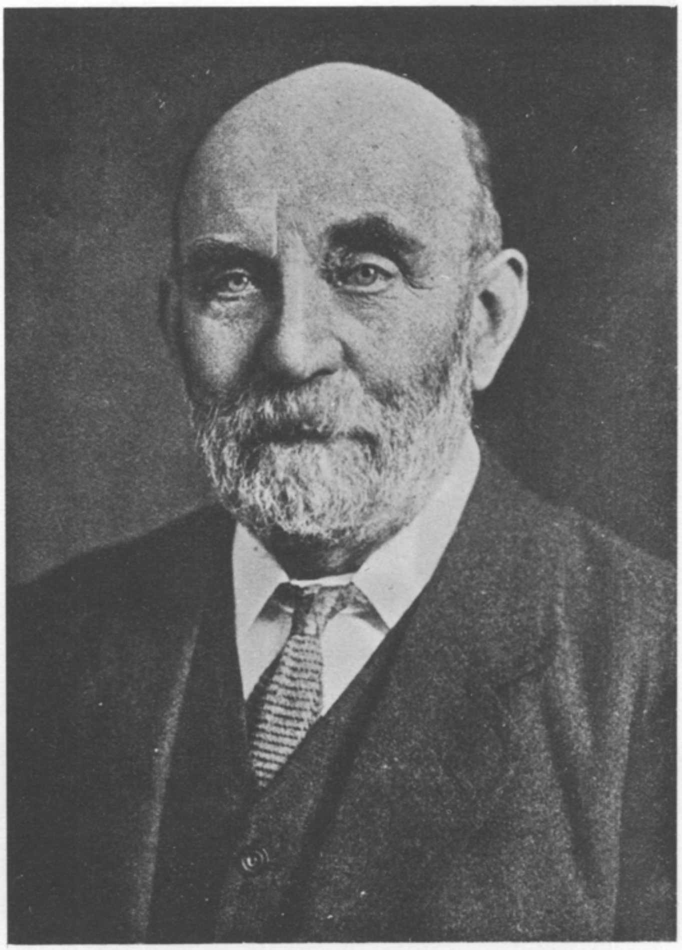
It was to accommodate the claims of Riley and of Snelus without resort to litigation that the younger men floated a company in 1882 – the Dephosphorising and Basic Patents Co Ltd – in which the patents of Riley, Snelus and Thomas were pooled and jointly exploited.

Edward Pritchard Martin (1844-1910) Born in Dowlais, where at the age of 16 he became apprenticed under W Menelaus and 9 years later deputy general manager of the Dowlais Works, E P Martin in 1874 was put in charge of the Blaenavon Ironworks.[18] At Blaenavon he had responsibility for installation of a Bessemer steel plant, and it was to this works that Percy Gilchrist came as chemist in 1877, shortly afterwards beginning for his cousin Sidney Thomas the experimental work that was to lead to the 'basic process'. Importantly, E P Martin provided active encouragement for the investigation.

Sidney Gilchrist Thomas (1850-1885) Born in London and having the advantages of a good home and school, Thomas from his late 'teens earned a living as a clerk in the Metropolitan police courts. With so much concerning Thomas being well said in other places, (19,20,21) biographical details here would be superfluous. Suffice it to recall that Thomas is stated to have been inspired to achieve the removal of phosphorus from liquid iron by a remark made by his evening-class tutor at the Birkbeck Institution, George Chaloner. Moreover, after Birkbeck, Sidney Thomas went on to study in the evenings at the School of Mines, off Piccadilly, where he passed various examinations and came into contact with the professor of metallurgy, John Percy. Thus he received some of the best instruction available in Britain and was in touch with the up-to-date ideas of the time.

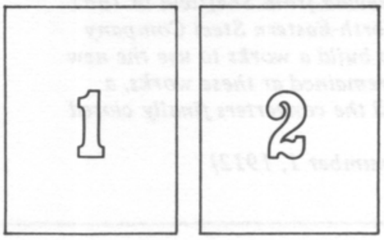
Percy Carlyle Gilchrist FRS (1851-1935) Sometime after studying at the School of Mines, where he obtained the Associateship in both mining and metallurgy, and towards the end of 1875, Gilchrist secured an appointment as works' chemist at Cwm Avon, near Port Talbot. It was soon after this, in 1876, that he was asked by his cousin Sidney Thomas for co-operation in carrying out experimental work to test his theories concerning phosphorus removal from liquid iron. Somewhat reluctantly, he agreed. But within a few months Percy Gilchrist changed his job, obtaining a post as analytical chemist at the Blaenavon Works. The story of the experimental work done by the two cousins, latterly with the active encouragement of the general manager of the Blaenavon Steel Co, Edward Pritchard Martin, is outside the scope of this article. But when, late in 1878, Thomas and Gilchrist had transferred their efforts to Middlesbrough (and Gilchrist had resigned his livelihood as works' chemist) it was still he who handled the day-to-day running of the tests, at the same time presumably doing much of the analytical work himself. Percy Gilchrist seems to have been content to leave to his cousin most of the publicity concerning their process, but after 1882 he consolidated the success they had then achieved by assuming the position of managing director of the company set up to exploit the patents covering the basic process. Throughout the next 20 years he did all he could to promote basic steelmaking by both converter and open hearth: he collated operating information from many licensed works, and had tests of basic-steel products made by Lloyd's Registry in an attempt to win wider acceptance for the material. He introduced to Frodingham the Czech, Maximilian Mannaberg. Unlike Sidney Thomas, after the momentous developments of the early 1880s, Percy Gilchrist lived for a further 50 years, although for many of them sadly incapacitated by ill health.

John Edward Stead FRS (1851-1923) Twenty years younger than E Windsor Richards but of similar age to Thomas and Gilchrist, and born on the Tyne, J E Stead attended evening



classes at Owen's College, Manchester, and then served an apprenticeship in Cleveland. After some years of chemical work on Tyneside he was appointed analytical chemist for Bolckow, Vaughan & Co. In this capacity he gained experience of Bessemer steelmaking, for the company at the time was operating a small plant at Gorton, Manchester. As early as 1876 Stead left regularly-paid employment to become a consultant chemist in partnership with John Pattinson, but he seems to have continued to give service to Bolckow, Vaughan: thus, in the autumn of 1878, Stead accompanied Windsor Richards on the fateful visit to South Wales that was to bring Thomas and Gilchrist to Cleveland. Moreover, in the arduous and frustrating months of effort to attain successful conditions of both liquid-steel product and vessel lining, it was most likely Stead who recommended the key procedural feature – the 'afterblow'. Amongst his many published researches, J E Stead included comprehensive articles on phosphorus in iron and steel. In addition to his life-long chemical practice, he was one of the pioneers of metallography, and was a stalwart promoter of facilities for technical instruction.[22]

Arthur Cooper (1849-1932) After an engineering apprenticeship in the Derby locomotive works, Arthur Cooper took up work in Sheffield with John Brown & Company where, before long, he was put in charge of the Bessemer steel department. In 1874 he left John Brown's for another Sheffield company, Brown, Bayley, & Dixon, where he gained experience in making tyres and rails. In 1879 he became involved with Thomas and Gilchrist's newly-proved basic steel-making technique when it was applied in one of the Bessemer plants of Brown, Bayley, & Dixon's works.[23] Two years later, in 1881, on the formation of the North-Eastern Steel Co in



1 **E Windsor Richards,** *manager of Bolckow, Vaughan and Company's iron and steel works in Cleveland, arranged for Sidney Thomas and Percy Gilchrist to transfer their investigations into phosphorus removal to his works in the autumn of 1878. In the subsequent development of commercial basic steelmaking by converter, Windsor Richards played a significant part, being responsible for many practical details contributing to success.*
(Portrait: Proc. IMechE, 1900)

2 **John Edward Stead,** *consultant chemist to Bolckow, Vaughan and Company, accompanied Windsor Richards to Blaenavon in October 1878 to access what Thomas and Gilchrist had on offer. In the following months of experimental work in Cleveland Stead is credited with suggesting the essential feature of the 'afterblow' to remove phosphorus in the converter. With his deep knowledge of the chemical aspects of the steelmaking process, he was able to offer much useful advice and support.*
(Portrait: Thomas and Gilchrist, Bolckow and Vaughan 1879–1929. Bolckow, Vaughan and Company Limited, Middlesborough, 1929)

Arthur Cooper *came to Cleveland from Sheffield in 1881 as general manager of the North-Eastern Steel Company which immediately began to build a works to use the new basic-Bessemer process. He remained at these works, a champion of basic steel until the converters finally closed in 1919.*
(Portrait: JISI, volume 85, number 1, 1912)

Middlesborough Arthur Cooper was appointed general manager, and later, managing director. This company, formed by Sidney Thomas and Edward Riley in association with others, specially to work the 'basic' process, started to produce steel sections in 1883. For a number of years the Cleveland businessman, Arthur Dorman, was chairman of the company. Arthur Cooper remained as managing director until 1919, the year in which the last basic air-blown steel in Cleveland was made at the works.

REFERENCES

1 **Thomas & Gilchrist, Bolckow & Vaughan 1879-1929.** (Middlesbrough: Bolckow, Vaughan & Co Ltd, September 1929), p.20.

2 E Windsor Richards, 'President's address'. **Proc. Cleveland Instn. Engrs.**, (November 1880), p.34.

3 Indenture between S G Thomas, G J Snelus, E Riley and the North-Eastern Steel Co Ltd, dated 21 July 1881. (British Steel Corporation, Northern Region Records Centre, 1978).

4 **Bolckow, Vaughan & Co Ltd,** report of 17th annual meeting. Manchester, March 1882. (Report, accounts, etc for 1881). p.22.

5 Arthur Cooper, 'Presidential address' **J Iron Steel Inst.**, vol.85 (1912), no.1, p.49.

6 **J Iron Steel Inst**, (1879), no.1. p.203.

7 E Riley, in discussion on open-hearth furnaces. **J Iron Steel Inst**, (1884), no.2, p.465.

8 T Gillott, 'The basic, open-hearth steel process'. **Mins.Proc.Instn.Civil Engrs.**, vol.77 (1883-84), pt.3, p.297-308.

9 J H Darby, 'The manufacture of basic open-hearth steel'. **J Iron Steel Inst**, (1889), no.1, p.78-83.

10 **Report on the Bessemer Process.** Iron Steel Inst. Spec. Rpt.42. (May 1949), appendix VII, p.75-6.

11 **Oxygen steelmaking.** (Thornaby, Teesside: Head Wrightson & Co Ltd, 1959).

12 **Iron and steel annual statistics for the United Kingdom, 1965.** (1966), table 43, p.46.

13 Figures for the period before 1889 are based on **British Iron Trade Association annual reports**; those for the period 1889 to 1935 are taken from Harbord, ref.19 below, p.95P; figures for the years since 1935 come from **Iron and steel annual statistics** volumes.

14 Obit. E Williams. **J Iron Steel Inst**, (1886), no.1, p.213-5.

15 Obit. E Windsor Richards. **J Iron Steel Inst**, vol.104 (1921), no.2, p.325.

16 Obit. Edward Riley. **J Iron Steel Inst**, vol. 90 (1914), no. 2, p.255-6.

17 'Mr George James Snelus', in **The creators of the age of steel**, by W T Jeans. (Chapman & Hall, 1884), p.317-335.

18 Obit. E P Martin. **J Iron Steel Inst**, vol.82 (1910), No.2, p.368-9.

19 F W Harbord, 'The Thomas-Gilchrist basic process, 1879-1937'. **J Iron Steel Inst**, vol. 136 (1937), no.2, p.77P-97P.

20 James Mitchell, 'Sidney Gilchrist Thomas a commemorative lecture'. **J Iron Steel Inst**, vol. 165 (May 1950), p.1-8.

21 S G Denner, 'The pursuit of crotchets. An appreciation of Sidney Gilchrist Thomas . . .' **J Historical Metall. Soc**, vol. 13 (1979) no.1 p.1 .6

22 Obit. J E Stead. **J Iron Steel Inst**, vol. 108 (1923), no.2, p.365-9.

23 Obit. Arthur Cooper. **J Iron Steel Inst**, vol. 126 (1932), no.2, p.426-7.

New light on the Bedlam Furnaces, Ironbridge, Telford

Stuart B Smith

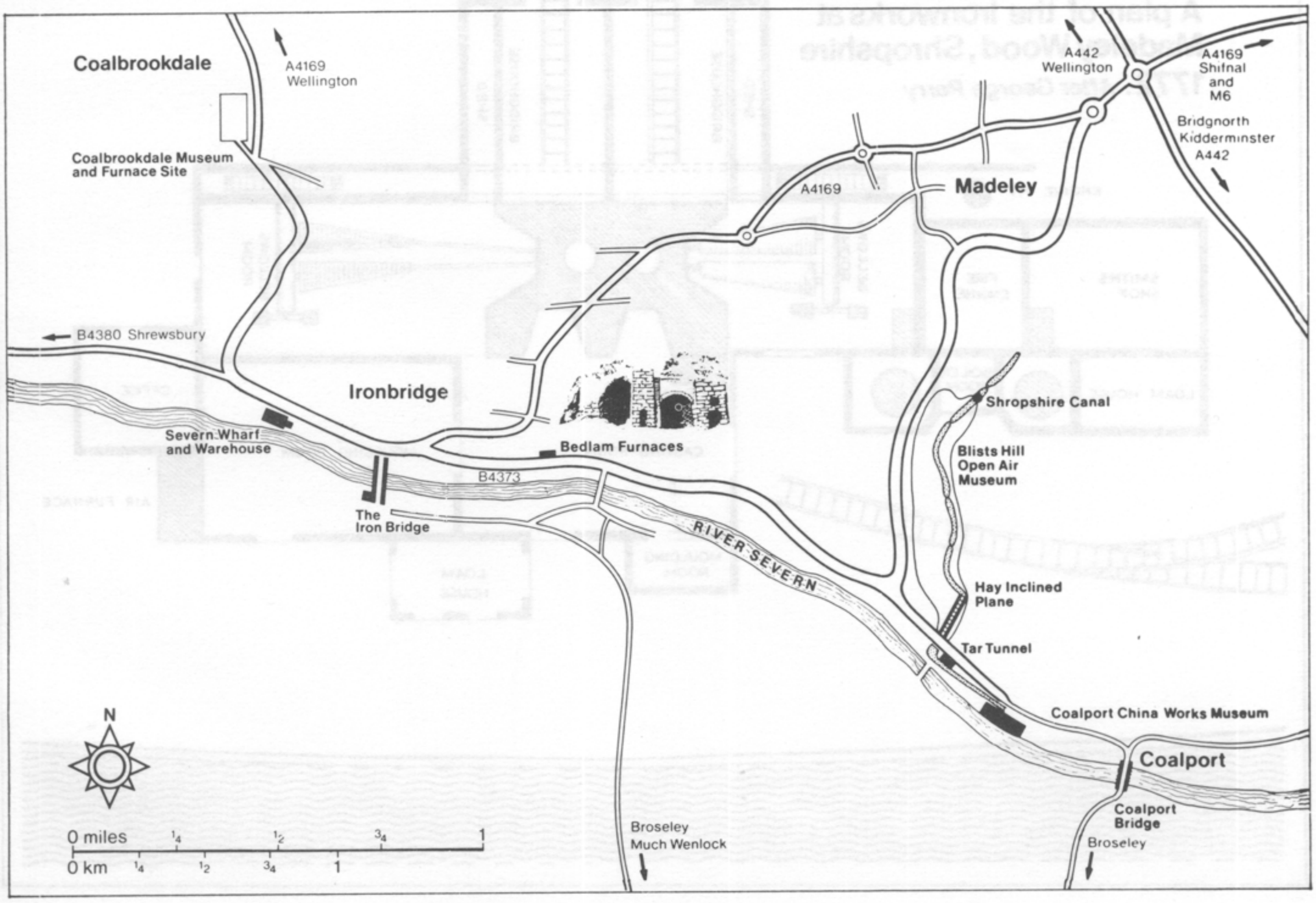
The Madeley Wood (alias Bedlam) Furnaces

The remains of the Madeley Wood ironworks stand on the north bank of the River Severn about 300 yards downstream from the Iron Bridge. The site is one of major archaeological importance. The blast furnaces at Madeley Wood were built in 1757-58, during the boom in the iron industry which accompanied the Seven Years War, in which coke blast iron was shown to be superior to that made with charcoal for almost every purpose. In the space of four years, following the commissioning of the Horsehay ironworks in May 1755, nine coke blast furnaces were constructed in the Shropshire coalfield.[1] Of these, the Madeley Wood furnaces are the only ones of which anything substantial remains. During 1971 the Ironbridge Gorge Museum obtained permission to excavate and consolidate these important ruins, and while this process is at present far from complete, a great deal of important evidence about the history of ironmaking has already come to light. At the same time the Museum has been making an inventory of all of the paintings and drawings of the Ironbridge Gorge made during the Industrial Revolution period. Close examination of some of these pictures has revealed further evidence about the Madeley Wood ironworks. It is the purpose of this paper to review the current state of knowledge of the works and to indicate some of the questions which may be answered by future investigations.

The Madeley Wood works was also known as the 'Bedlam' ironworks, but this title probably owes nothing to the heat, dust and noise of the ironworks. An adjacent Jacobean house was known as Bedlam Hall, and it seems to have borne this name long before the ironworks came into existence.

The documentary evidence for the history of the Madeley Wood ironworks is not extensive. There is a consecutive run of production figures only for the period 1790-97.[2] Annual statements of the Madeley Wood Company indicate how much iron was produced from 1826 onwards, but after 1832 it is impossible to separate figures for the Bedlam works from those of the Blists Hill ironworks. It is nevertheless possible to establish the broad chronology of the development of the works, and to devise from the documents some of the principal questions to which archaeological and pictorial evidence may be able to provide answers.

The original Madeley Wood Furnace Company was established in 1756, and brought its two blast furnaces into operation in 1757-58. The Company was made up of local people, none of the 12 partners living further from the works than Bridgnorth. They included John Smitheman, landlord of the site and Lord of the Manor of Madeley, William Ferriday of Buildwas, agent to the Forester family and a partner also in



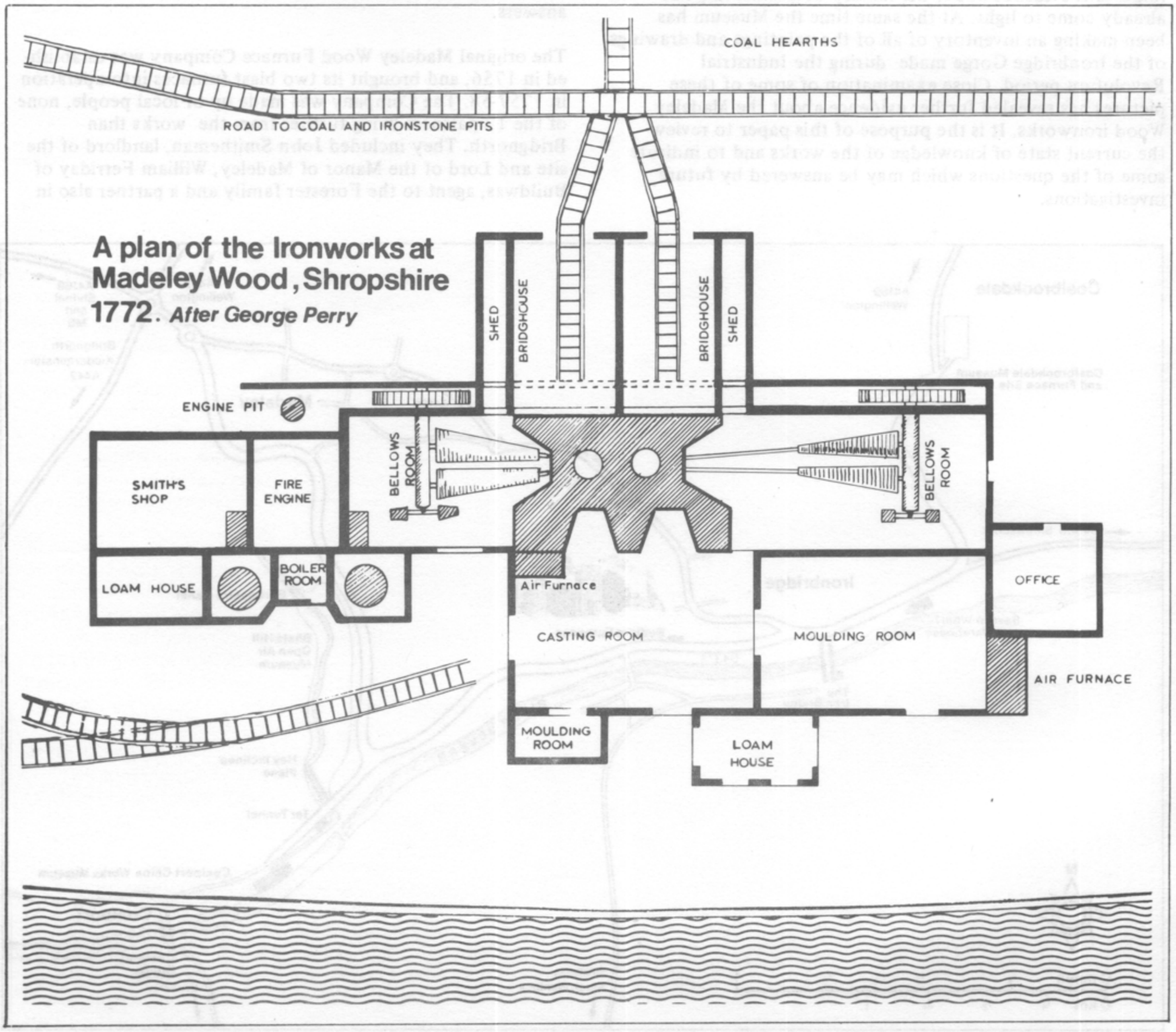
the contemporary New Willey and Lightmoor concerns, Edmund Ford, member of a Quaker family with long connections with ironmaking at Coalbrookdale, Leighton and elsewhere, and three local master colliers.[3]

The 19th century local historian and geologist John Randall, who remembered the furnaces working, said that they were situated "at the base of the outcrop of the lowest seams of coal and ironstone",[4] a fact which has been confirmed by recent geological investigations.[5] The lowest seam of iron ore in the area is the Crawstone, an ore which makes a particularly good melting iron. Throughout its history the Madeley Wood works was renowned for the quality of its foundry pig,[6] and probably from its very beginnings it specialised in this type of iron. Madeley Wood was the only one of the ironworks established in Shropshire in the 1750's which did not sell some of its iron to the forges in Worcestershire owned by the Stour Valley partnership.[7]

The economic function of the Madeley Wood ironworks was to provide a profitable consumption for a high proportion of the produce of the Madeley Field mines. It was part of a complex network of enterprises raising income through the sales of domestic coal, lime and limestone, and bricks, as well as through the products of the ironworks. It is important to an understanding of the history of the works to acknowledge that it existed to serve the mines rather than to be served by them. The Madeley mines existed long before there were ironworks for them to supply, and they continued after the furnaces were finally blown out.

In 1772 a plan[8] was drawn of the works showing two blast furnaces, a foundry, railways, and riverside quays. Four years later the leases of the works and the adjacent mines were made over to Abraham Darby III,[9] builder of the Iron Bridge, and for the next two decades they were an integral part of the Coalbrookdale Company. By the 1790's the company was experiencing difficulites in the Madeley mines, and the great partnership was showing distinct signs of strain, being as a whole largely unprofitable. In consequence, in July 1796 the concern was split between the Darby and Reynolds families, the Madeley Wood works going to William Reynolds. After Reynolds died in 1803 it passed to William Anstice, son of Robert Anstice who had married Reynolds' cousin Susannah Ball.[11] The Anstice family retained control of the Madeley Wood Company until well into the 20th century.

In the 1830's and early 40's the ironmaking concerns of the


A plan of the Ironworks at Madeley Wood, Shropshire 1772. ***After George Perry***

Madeley Wood Company were moved from the side of the Severn to Blists Hill, nearer to the mines then being exploited, and well sited to be supplied by canal. The remains of the blast furnaces, and of two engine houses, one dated 1840, survive at Blists Hill. John Randall considered that the furnaces were built in 1832, 1840 and 1844, and the slight manuscript evidence which survives suggests that the chronology is not far from accurate. The annual statements of the Madeley Wood Company show that in the year 1832-33 sums of money were written off towards the expense of a new furnace, and further expenditure for the same purpose is recorded in 1840. The record of iron production in the period further confirms these developments. In 1832-33 production exceeded 5000 tons per annum for the first time, the previous best being 3,800 tons. In 1839-40 it again reached a record level, 7,900 tons.[13] It is impossible to ascertain from these slight surviving records what happened to the Madeley Wood furnaces while those at Blists Hill were being brought into commission, but it is likely that they continued in production during the 1830s. The existence of four blast engines on an inventory of the Madeley Wood Company's stock in 1842[14] suggests that both the Bedlam and Blists Hill concerns were then working, or at least capable of working. It is likely that the former ceased production not long afterwards, perhaps when the last Blists Hill furnace came into blast in 1844. By 1849 the Madeley Wood Company was reckoned to have three furnaces only, without doubt those at Blists Hill.[15] Much of the Bedlam works was deliberately destroyed or filled in with rubbish from the neighbouring gasworks established in 1840. One of the furnaces was used for a time as a brick kiln, and the site was a favourite venue for fairs in the late 19th century.[16] By the 1930s it was entirely overgrown.

The Bedlam furnaces thus had a working lifetime of about eight decades. They are the remains, not of an installation which once built was never altered, but of a process which was constantly being improved through the Industrial Revolution period. Any archaeological investigation of the site needs therefore to aim at presenting a dynamic rather than a static picture of the works. The extent of change in the period during which the furnaces operated is nowhere better demonstrated than in the production figures for blast furnaces. At the nearby Horsehay works, the best documented in the district, an output of over 20 tons of pig iron a week per furnace was reckoned to be an excellent result in the 1750s, by the first decade of the century over 50 tons was being achieved, and an output as high as 65 tons a week was reached in the 1830s, even before the introduction of hot blast.[17] Many of the improvements in furnace technology between 1750 and 1830 are scarcely documented at all, and the Bedlam site offers an opportunity to detail just how one particular group of furnaces was altered over a period of eight decades.

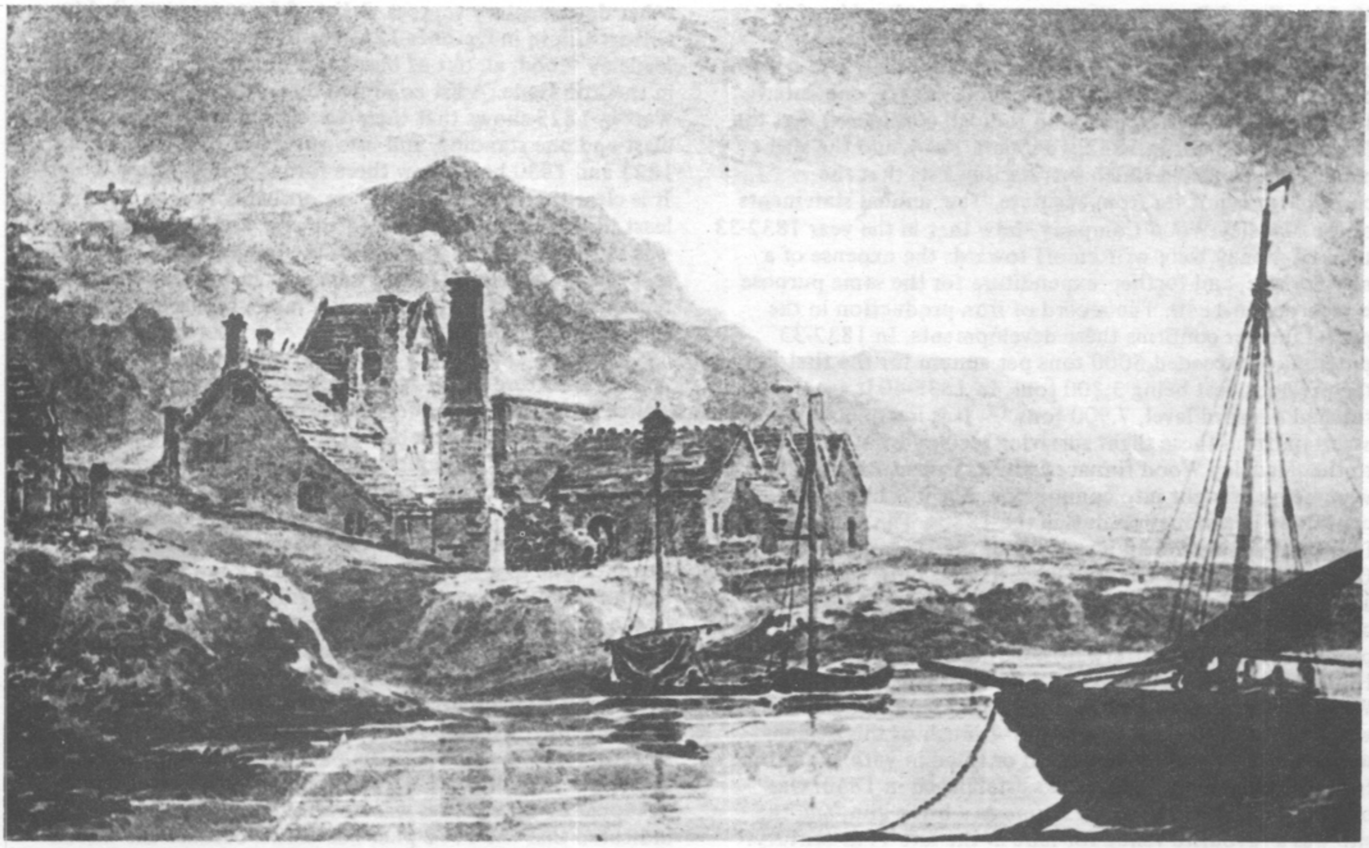
The first and most basic of the questions to be asked about the Madeley Wood works, concern the extent and scope of the enterprise. It is clear that there were two furnaces on the site from the beginning, which are shown, together with a small foundry on the plan of 1772. The foundry, capable in the 1790s of casting parts for steam engines, went out of use shortly before the death of William Reynolds in 1803.[18] One of the furnaces was taken out of blast in 1794 at a time of declining trade, and only one was operating there in 1796.[19] This furnace may have been rebuilt about the end of the decade, for a list of new furnaces of 1801-02 shows one at Madeley Wood recently completed. There remained only two on the site at this time, for lists of 1804 and 1806 both record only two furnaces at Madeley Wood.[20] By the time Thomas Butler visited the area in 1815 there were three furnaces at the works,[21] and this is confirmed by several other documentary sources. A list of furnaces compiled by Gilbert Gilpin in October 1817 shows three furnaces at Madeley Wood, all out of blast, at a time of deep depression in the iron trade. A list compiled for Messrs Boulton and Watt in 1825 shows that there were then two furnaces[22] in blast and one standing, and lists published by Scrivenor for 1823 and 1830 both show three furnaces at Madeley Wood. It is clear therefore that there are probably the remains of at least three furnaces on the Bedlam site, and if a new furnace was built about 1801 in place of the one taken out of use in 1794 there may be four. There may in addition be some remains of at least two air (reverberatory) furnaces which formed part of the foundry.

A unique feature of the Madeley Wood ironworks was the source of power for the furnace bellows. All of the contemporary works in the area had bellows operated by waterwheels, the water for which was stored in reservoirs, and recirculated from pools below the waterwheels to pools above them by Newcomen steam engines. At Bedlam, water for the wheels was pumped direct from the Severn by a steam engine to a reservoir, from which it ran into a race behind the furnaces. What is probably the original layout of the waterwheels is shown on the plan of 1772. In the sale of 1776, two fire engines are mentioned. John Randall in 1880 wrote that the race in which one of the wheels worked could still be seen, together with the arches which supported the reservoir.[23] It is possible that a substantial stone structure which survives to the west of the furnaces is part of this reservoir, but the 1776 sale indicates that a house occupied by John Jones was now the 'Poole'. Possibly this indicated that the 1772 plan was drawn because the wheels were short of water and was followed by the installation of a new fire engine and the creation of a new pool.

Soon after 1780, when the Bedlam furnaces were under the control of the Coalbrookdale Company, it seems that a new Boulton and Watt steam engine with a 48 in x 8 ft (1.2 x 2.45 m) cylinder, and estimated to be of 50 hp, was installed,[24] probably to blow the furnaces direct. There must remain some doubt about this development, however, for a letter of 1796 from William Reynolds and Co to Boulton and Watt said that no payments would be made on the Madeley Wood engine since alterations (perhaps to conform with Watt patents) had not yet been made.[25] Current work on the Boulton and Watt papers may provide documentary evidence of what happened, but the archaeological evidence will clearly be of great importance in determining what changes took place.

Another important aspect of the works on which excavation should throw more light is its transport systems. When the works was built there was no road along the riverside, and adjacent to the Severn are probably remains of the quay shown on the 1772 plan. The furnaces were approached at a high level on the landward side by railways, and the course of the line to the east appears still to be marked by a footpath. How were the raw materials brought by the railways conveyed to the tops of the furnaces? And were the furnaces built into the slope of the side of the gorge, or were they free standing? And how was the limestone delivered by river from Much Wenlock and Buildwas conveyed to the top of the furnaces?

The 1772 plan shows what appears to be a railway tunnel immediately to the west of the furnaces, so steep that it probably contained an inclined plane. Its purpose was to convey to the quay domestic coal for Severn sale. It is likely that this tunnel will come to light during excavations. Numerous plate rails have already been found at Bedlam, and and it is known that they were cast at the works in the 1790s



Bedlam Furnaces c1780 attributed to Edward Dayes

1790s, but it is possible that some examples of the first type of iron rails, the thin edge rails introduced in 1767, may be found there. It is certainly very likely that the railways serving Bedlam were laid with this type of track, before the introduction of the plate rail in the late 1780s.[26]

Finally, a most important feature of the history of the Madeley Wood works was its connection with early experiments in making coke in closed ovens, and thereby utilising the by-products, rather than making it in open heaps. When Abraham Darby III bought the works in 1776 there was a 'range of coal tar buildings' on the site, but these were apparently unsuccessful and ceased to be used after 1779. Between 1784 and 1786 the great pioneer of the destructive distillation of coal, Archibald Cochrane, 9th Earl Dundonald, built banks of coke and tar ovens at the Calcutts and Bentall Ironworks in the Ironbridge Gorge. In 1786 William Reynolds invited him to build similar kilns at Madeley Wood.[27] By February 1789 the kilns were complete and producing coke, it is doubtful whether they enjoyed a long life however. It is thus possible that excavations at Bedlam may reveal not only remains of the Dundonald process, but of the earlier means of making coke and tar which Darby found in operation when he bought the works in the 1770s before Dundonald first came to Shropshire.

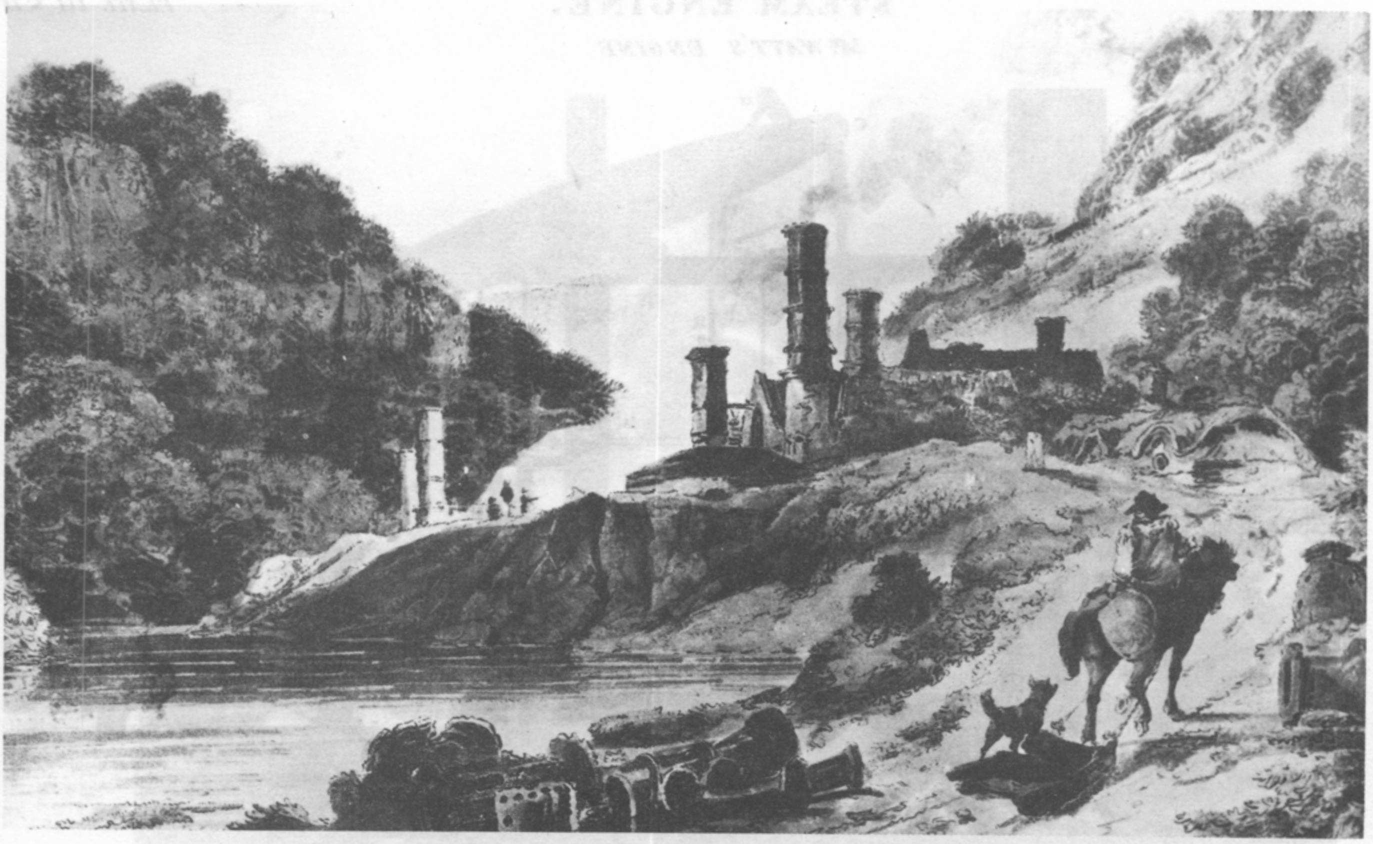
THE EXCAVATIONS

Before work started on site, only a very small amount of the furnace complex was visible and subsequent excavation exposed about one third of the whole. In no area has excavation been taken down to below mid-nineteenth century levels. Work to date has been concerned with exposing and consolidating the surviving above-ground structures of the site.

The Furnaces

The site is immediately alongside the present B4373 Ironbridge to Broseley Road, and the River Severn. There is now a gentle slope down from the road to the furnace mouth which covers the casting area. As can be seen on the 1772 plan, the casting house abutted the furnace and evidence of this can be seen on the masonry and by the unique chimney or vent formed in the furnace stack immediately in front of the tap hole of the western furnace. The front of this furnace lining has completely collapsed but the rest of the lining stands to a height of approximately twenty feet. The remains of the last charge still lie in the hearth and one wonders whether the furnace closed because of the collapse of the tapping arch. The tap hole and slag notch are still visible and the presence of iron plates around the tap hole (now in store at Blists Hill) may indicate that it was an open dam furnace. Detailed archaeological excavations of the forehearth area should confirm this point. Due to the fact that the last charge is still in this furnace, it is impossible to take any dimensions of the hearth and crucible, but sufficient remains of the rest of the lining to draw a hypothetical section. The bosh angle is almost non-existent indicating, as one would expect, a lining dating from the early nineteenth century. The diameter of this furnace is approximately ten feet (3.0m) at the bosh. The eastern furnace, of which only the bottom six feet (1.8m) stands unaltered (the top portion being later used as a brick kiln) has a diameter at the tuyeres of 5 feet 2 inches (1.57m). The crucible is not yet excavated.

Both furnaces have three tuyeres, although originally (as shown on the 1772 plan) they had only one tuyere. The adjacent tuyeres of both furnaces are reached via a short passage through the furnace stack, which opens out into a vertical shaft. This passage continues into the back of the



Iron Works, Colebrook Dale 1805 William Picket after Philippe Jacques de Loutherbourg

furnaces into a collapsed passage in which still lies the cast iron blast main. Each tuyere is of cast-iron, not water cooled and of the design shown in Rees, Cyclopaedia, Plate X, chemistry, Blast Furnace, Fig. 7. There is no evidence of the way in which the air was conducted into the tuyeres. Both furnaces show a double tuyere arrangement at the back of the furnace, one above the other. The tuyeres are at differing heights as shown by the following table.

	West Furnace	East Furnace
Rear Tuyere (1)	1.93 feet (0.59m)	
Rear Tuyere (2)	1.25 feet (0.38m)	
East Tuyere	1.19 feet (0.36m)	NOT YET
West Tuyere	0.82 feet (0.25m)	EXCAVATED
Slag Notch	0.56 feet (0.17m)	
Tap Hole	0 feet (–)	

As yet the forehearth of the eastern furnace has not been excavated but should reveal more evidence than the others. The tuyere arch of the rear tuyere on the western furnace still retains the two iron beams whereas all the other arches have been robbed. Access to the rear tuyeres is only gained via a short passage from the west tuyere on the Western furnace and via an, as yet unknown route, to the eastern furnace. There is no indication that there was any ventilation to this tuyere arch and it shows every sign of being a later addition.

Blowing Arrangements

The western bellows room shown on the 1772 plan still survives relatively unaltered. Immediately opposite to the tuyere are two openings in the brickwork (one filled in) which could have received the ends of the bellows. Access from this room to the waterwheel pit is via a small doorway through which the axle of the wheel must have passed. Inside the bellows room is still the timber base, cut out for the bearing of the waterwheel.

The waterwheel pit, 28'8" (8.75m) long and 3'7" (1.10m) wide is now bricked over with a barrel arch at axle level and internally rendered. To the west of the pit is an arch approximately thirteen feet (4 m) above the axle over which the water supply probably came.

The 1772 plan shows a wheel of about twenty-five feet (7.6m) diameter and three foot six inches (1.06m) width so one cannot be certain whether the wheel was high breast or overshot. As this pit has been re-used at some time for another purpose it is to be hoped that excavations on the other side of the furnaces might reveal more information on the other waterwheel.

The bottom of the waterwheel pit is connected by underground culvert to the river bank where the opening can still be seen.

Although there is a small culvert above the furnaces which brought some water to the site, the bulk of the water supply came from the river by means of a pumping engine. The brick pumping shaft of this engine has been partially excavated and almost certainly extends to below river level. The original Newcomen Engine pumped from this shaft to a reservoir from whence it was led to the waterwheel. The massive wall which supported the fulcrum of the pumping beam is still to be seen as are the marks on the walls indicating where intermediate floors were situated. Excavations have not yet reached the floor of this engine-house nor has any evidence of the boilers been found.

STEAM ENGINE.

PLATE III & IV

Mr. WATT'S ENGINE

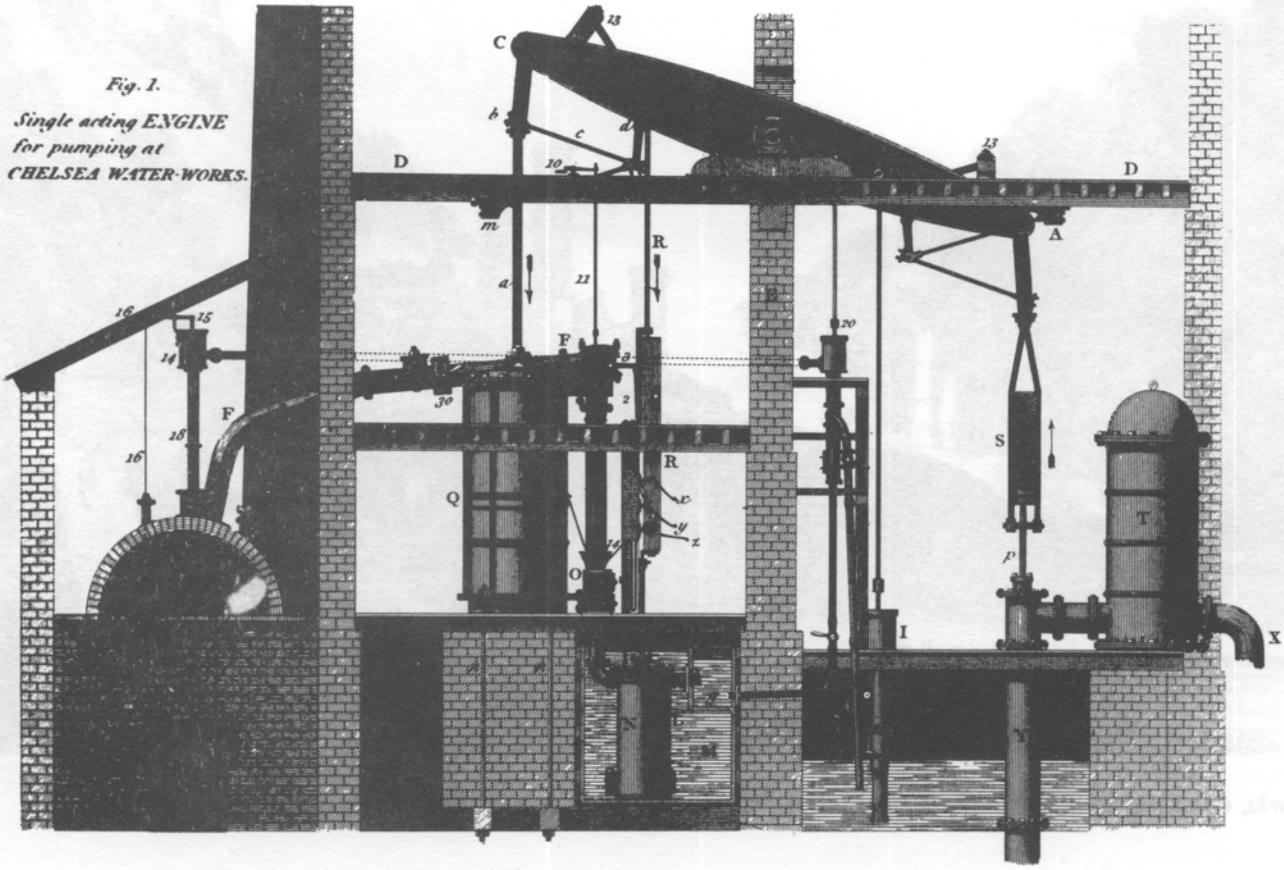


Fig. 1.
Single acting ENGINE for pumping at CHELSEA WATER-WORKS.

What is even more surprising is that no evidence of the possible Boulton & Watt direct blowing engine has come to light. Is it possible that the Newcomen Engine was left in situ and that the new engine was situated on the eastern side of the complex where no excavation has yet taken place? It is certain that the eastern furnace was taken down and moved east to accommodate a further tuyere and so it is quite possible that the replacement of this waterwheel by a new engine happened at the same time.

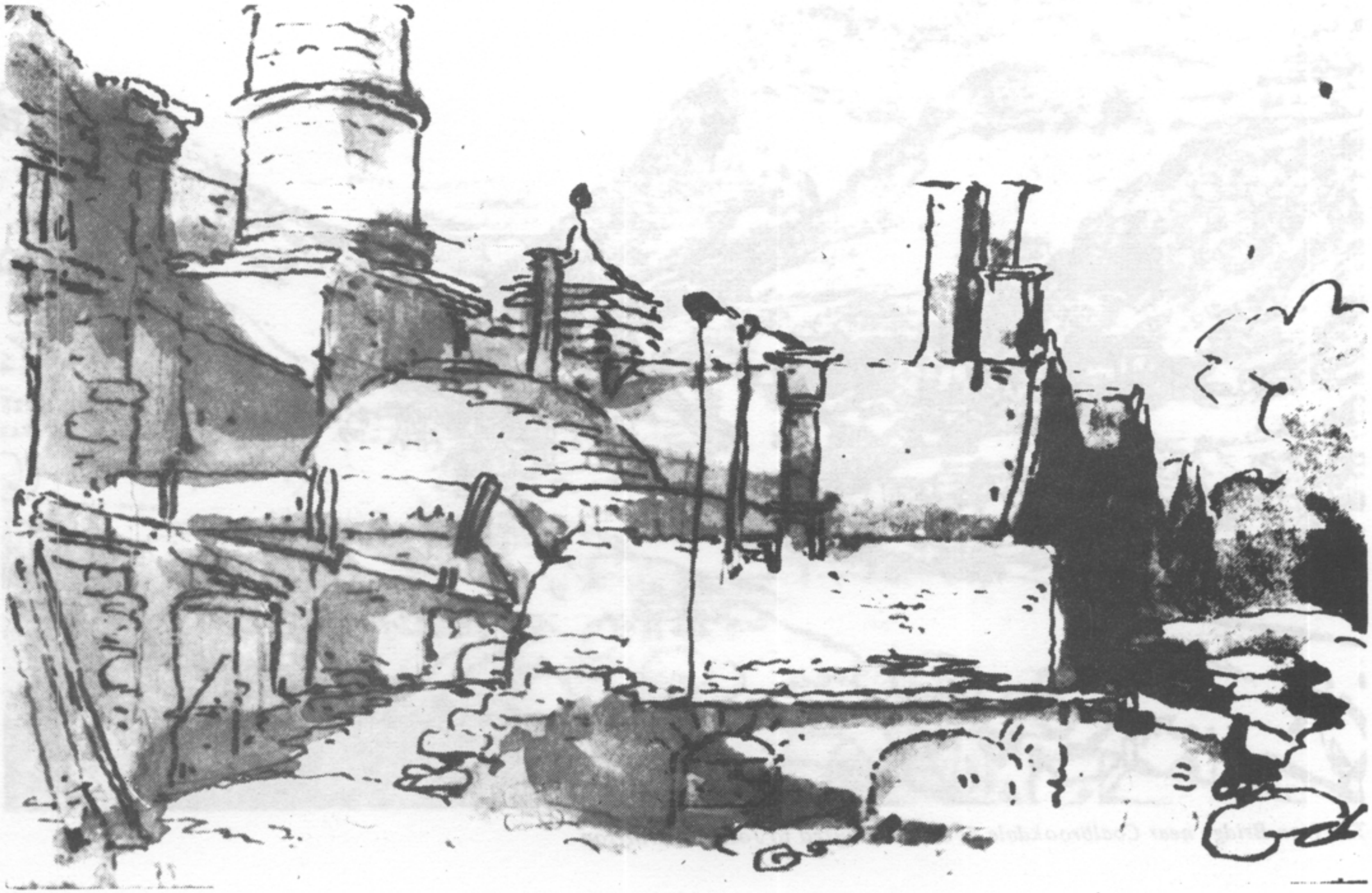
Possibly the most fascinating mystery is the subsequent use of the western waterwheel pit. As stated before, this pit has been arched over and internally plastered. There is one opening into the pit directly below the waterwheel axle position. In 1776 John Wilkinson had built the first direct blowing engine at New Willey fitted with a blowing regulator. A blast regulator is known to have been working at Hollinswood in 1793. Rees Cyclopaedia contains many illustrations and descriptions of air chambers and blast regulators. Is it possible that the waterwheel pit at Bedlam was used for this purpose after the removal of the wheel? Further excavation may prove the point and solve many other problems.

BEDLAM IN ART

Several paintings and sketches have been done of Bedlam Furnaces, mainly by eminent artists. When they are studied together with contemporary plans, a clearer idea of the development of the site comes to light.

The earliest drawing is not dated and had been previously ascribed to Turner. It is in a collection of doubtful drawings in the British Museum and has been recently identified as being by Edward Dayes (1763–1804). It was probably executed in the mid 1780s as this is when he was most active. Therefore the illustration should relate to the 1772 plan rather than the 1840 plan as a considerable amount of re-building took place at Bedlam in the periods 1780-1800 and 1806-15.

The drawing, made from either the opposite bank of the Severn or from the byelet island in the river (as shown on the plan of 1772), shows one trow in the foreground and two moored in front of the furnaces. On the extreme left of the group of buildings, is one with a pitched roof from which there is a further catslide roof angled towards the river. This building could be identified with the Smith's shop and Loam shop of the 1772 plan. A chimney is protruding from this roof in the correct position to relate to a possible Smith's hearth shown on plan. Slightly downstream of this building is a three storey building with gabled roof pointing towards the river. This is identified by its size and window type as an engine house. Once again this agrees with the 1772 plan. In front of this building is a substantial square stepped chimney which does not relate to the plan. It is known that by 1776 a further engine had been installed and possibly by 1781 the Boulton & Watt engine and this chimney may have been built to serve the increased boilers. Adjacent to the engine house is a rectangular building with no roof which will be the furnace and bellows house. Immediately in front of them is a group of buildings with ridge and furrow roofs dividing the building into four bays. This relates directly to the casting room and moulding room of the 1772 plan, with the suggested casting room even having a ventilator in the roof. On the river side of this building is a small lean-to which can be identified with the loam house on the plan.



Fire Engine, Coalbrookdale 1800 Philippe Jacques de Loutherbourg

The furthest building downstream is a small building of which only the roof is visible. This is almost certainly the office shown on plan. The only obvious deviation from the 1772 plan is the chimney but it is not clear from that plan where the chimney was. Perhaps evidence will eventually come to light to date the picture more accurately. It does however show a much smaller works than the Farington sketch of 1789 which is the first accurately dated illustration. In this pencil sketch attributed to Joseph Farington (1747-1821) for an oil painting (since lost) of **The Iron Bridge near Coalbrookdale**, which was drawn from somewhere near Blists Hill, one can just discern the faint out-line of Bedlam Furnace and the words **Bedlam Furnace** are written on the sketch alongside other annotations.

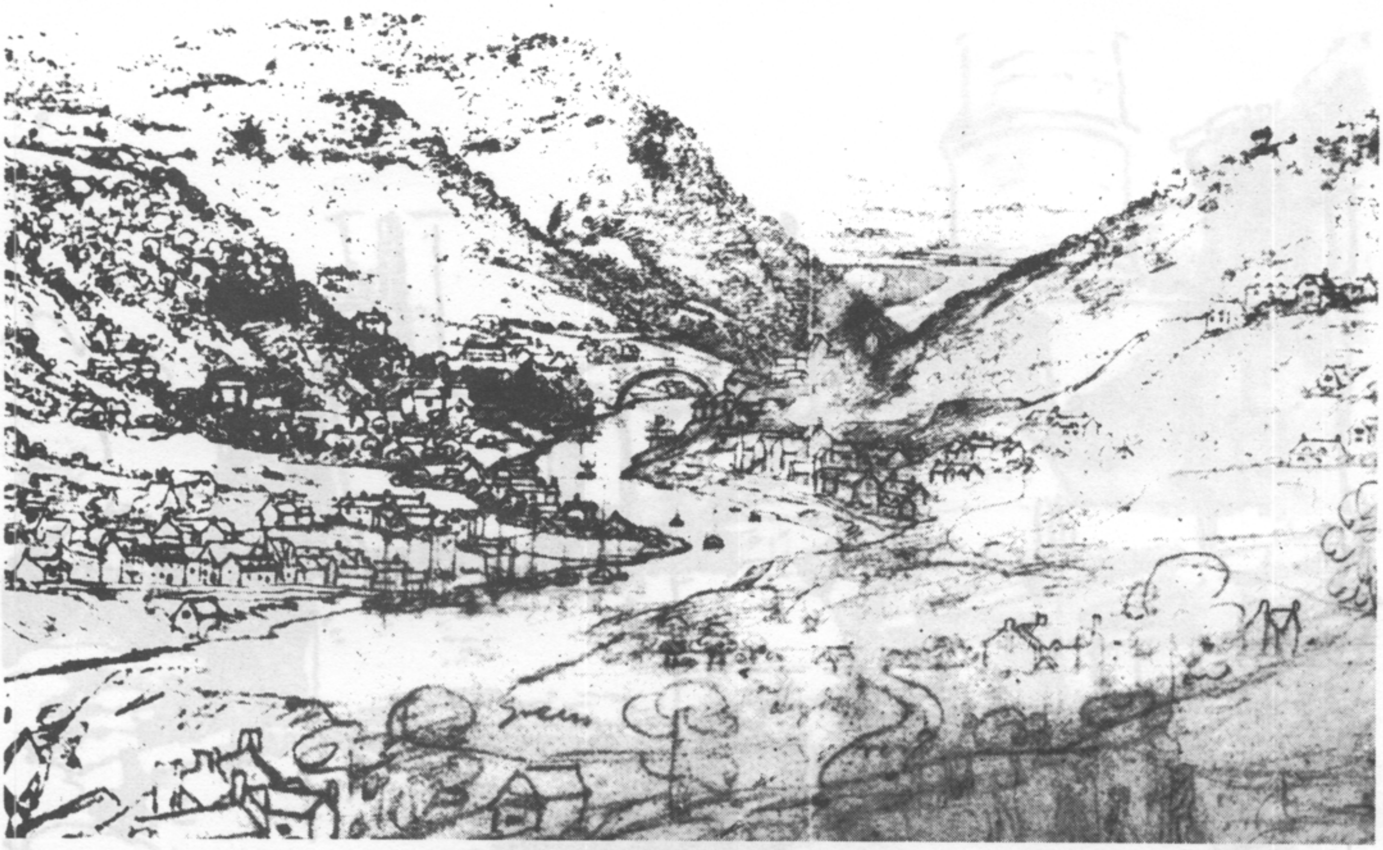
The date of the sketch is September 25th, 1789, and on the same tour of Shropshire he sketched in Bridgnorth and at the Lady Oak near Cressage. Although the sketch is not signed, the fact that he was in the area at the time and the precision of the drawing make it almost certain that it was by Farington, a most accomplished topographical artist.

The sketch shows two clusters of buildings around the coke hearth, two with prominent gables facing the river. Only one chimney is visible and there is a large building, parallel to the river which may be the bridge house. As the view point is from the Blists Hill valley, the buildings nearest to the artist are those downstream of Bedlam, the opposite view point from the Dayes sketch. The land appears to lie in two plateau's behind the furnaces, roughly corresponding with the coke hearth areas shown on plan. It does, however, seem obvious that considerable building has taken place since the 1772 plan and the Dayes sketch. From the drawing it appears that the majority of the buildings shown on the 1840 plan are already built with the exception of the chimneys and boilers.

For nearly two centuries, one of the most famous oil paintings which has epitomised both the horror and excitement of the Industrial Revolution, has been that by Philip James de Loutherbourg of **Coalbrookdale by Night.**

Until very recently the exact location of this wild and romantic view of early industrialisation has been uncertain, but new evidence has now come to light to prove that it depicts Bedlam Furnaces.

De Loutherbourg (1740-1812) came from Paris to London in 1771 when he was already an established artist and with a letter of introduction to Garrick he was soon designing scenery for Garrick and Sheridan. He was very interested in mechanical stage sets and was one of the first to introduce artificial effects on the stage to produce fire, thunder, emptying volcanoes and other dramatic events. By 1781 he had designed a series of moving pictures with sound effects called the Eidophusikon with which he hoped to make nature larger than life. With his interests in such matters, it is not surprising that **Coalbrookdale by Night** is such an exciting picture with the flames even hotter and the houses even more rustic than even Coalbrookdale must have been in the late eighteenth century. Between 1788 and 1799, De Loutherbourg only produced foreign scenes, so his visit to Coalbrookdale must have been in 1880 as he exhibited this painting at the Royal Academy in 1801 (54, as 'A View of Coalbrookdale by Night'). He also did several other sketches of engines and foundries in the area, now in the British Museum, only one of which can be possibly associated with Bedlam.



The Iron Bridge near Coalbrookdale 1789. Attributed to Joseph Farington

Coalbrookdale by Night depicts Bedlam furnaces from a view point on Waterloo Street, fairly close - to the present day coach depot and looking along the river bank towards the Severn. The red glow in the centre of the picture is from the coke hearths which were behind the furnaces, and the houses on the left of the picture, were demolished to build the Ironbridge Gas Works. The moon rising over Broseley contrasts with the glare from the open furnace tops and the coke heaps.Bedlam was of course in Coalbrookdale, for Coalbrookdale was often the name given to the entire Severn Gorge.

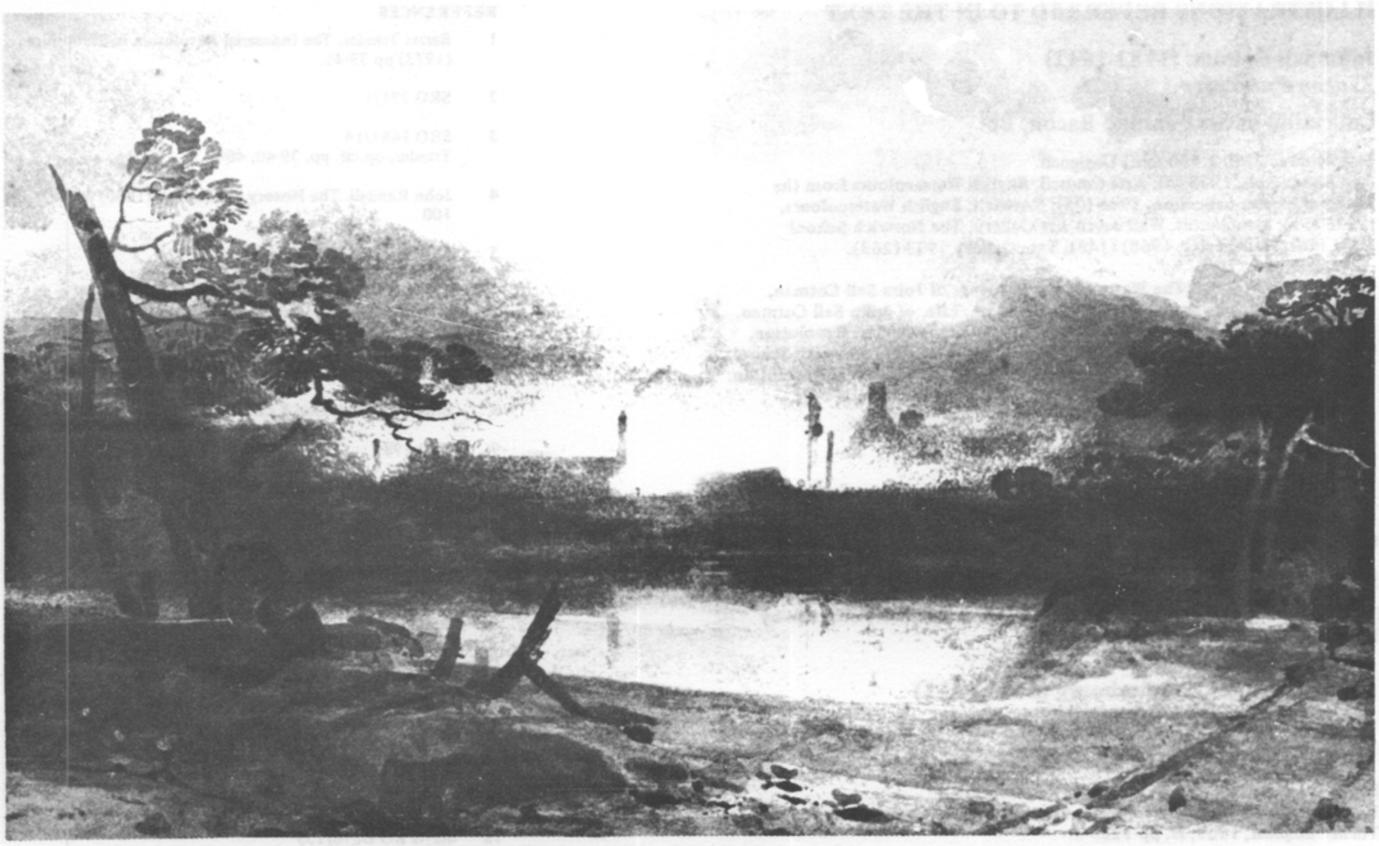
De Loutherbourg also executed another painting of Coalbrookdale, simply entitled **Iron Works, Coalbrookdale** which was produced as an aquatint by William Pickett (Active 1792-1820) in 1805. The subject matter is very similar in theme to **Coalbrookdale by Night** and from the shape of the chimneys and the positions of the water on the left of the picture, it is more than likely that it is also a picture of Bedlam Furnaces but looking upstream.

In the foreground is a group of buildings with two circular chimneys and two smaller square chimneys. At least three parallel roof lines can be seen in this group all running at right angles to the river. In front of these buildings is a delapidated thatched cottage, slightly further away from the river than the other buildings. The 1840 plan shows a similar arrangement of buildings on the downstream side of the furnace. In the plan there are four small squares that could be chimneys and two circles that may be either chimneys or haystack boilers. In the illustration there is a large, possibly spherical building, with domed brick roof, in front of the other buildings. The juxtaposition of chimneys, buildings and old cottage is easily identified on plan.

In the left middle distance, beyond the glow of the furnaces, can be seen two more chimneys and a group of buildings, almost certainly the old boiler house chimney shown in Dayes sketch.

De Loutherbourg's sketch of a **Fire Engine in Coalbrookdale** is one of a series of pen and ink sketches done by him in 1800 and more similar in detail to Bedlam than the other sketches. The arrangement of boiler houses, chimney, ridge and furrow roofs is reminiscent of the foreground of the Dayes illustration and in particular the ventilator on the first gable of the possible casting house. The prominent brick domed structure, also shown on **Coalbrookdale by Night** is almost certainly a haystack boiler whereas the boiler in the foreground with safety valve is of the horizontal type and was probably installed in conjunction with the Boulton and Watt engine. The large pipe leaving the back of the boiler is the steam main and the vertical pipe is the water intake from the condenser with the vertical rod operating the float valve. Compare this drawing to Plate III and IV Steam Engines, Mr Watts Engine, Rees Cyclopaedia Vol. XLIII.

In the week 11-20th July 1802, two artists visited Coalbrookdale en route to the great sketching country of North Wales, they were John Sell Cotman (1782-1842) and Paul Sandby Munn (1773-1845). They both drew Bedlam Furnaces as well as the Iron Bridge, coal shafts on Lincoln Hill and views in Coalbrookdale. Their respective views of the furnaces are in marked contrast. Munn chose the same vantage point as De Loutherbourg and drew a very realistic picture of the furnaces. Gone are the vivid reds of De Loutherbourg and in their place a more autumnal picture of browns and greens with dull brown smoke rising above the white haze of the coke hearths. The buildings and industrial debris are clearly the same as those shown by De Loutherbourg but as Munn was not painting for a stage set the whole effect is more realistic and pastoral.



Bedlam Furnace, near Madeley 1802 John Sell Cotman

Cotman went over the Iron Bridge to the Broseley side of the River Severn to obtain his vantage point but his picture is more abstract in character than Munn's. It shows a clearing in the wooded banks of the river through which one can see the misty glow from the furnaces. It conveys little information and yet just like De Loutherbourg creates an atmosphere which inspires or dismays the viewer depending on one's attitude to industrialisation.

Painted in 1802 when two furnaces were working, the illustration shows a long low building to the left with three small chimneys at one end and a much larger one at the other. In the centre of the picture is the glow from the furnaces and coke hearths with two taller chimneys and a substantial building, gable on to the river, on the right.

The 1840 plan could relate to this illustration, vague though it is, as the Smith's shop and boiler house had a chimney and three more are grouped on the downstream side of the works.

The paintings by Cotman and Munn convey little factual information about the furnace site but the fact that the Munn picture is titled **Bedlam Furnaces**, allows one for the first time to correctly locate De Loutherbourg's **Coalbrookdale by Night**.

Chronology of Bedlam Furnaces

1756	Madeley Wood Co established
1757	Two furnaces working
1770's	(Boom in Iron Trade due to American wars)
1772	Plan: 2 furnaces, 2 water wheels, 2 boilers, 1 engine, 2 sets of bellows
1776	Leased by Abraham Darby III, 2 furnaces, 2 fire engines, pool – late John Jones House, new machine house
1776	(Wilkinson erects first direct steam blowing engine at New Willey with water regulator)
C1781?	Boulton & Watt engine installed for direct blowing
1780s	Drawing by Dayes
1789	Drawing by Farington
1790s	(Boom in Iron Trade due to French wars)
1793-6	Works transferred to William Reynolds
1793	(Hollinswood Blast Regulator by William Reynolds)
1794-7	1 furnace out of blast, 1 working, producing 130-160 tons of iron per month
1795	Production 1624 tons of iron in the year
1796	Only 1 furnace working
1800	De Loutherberg painting, 'Coalbrookdale by Night'
1801	2 furnaces, one recently completed
1802	Paintings by Cotman and Munn
1803	2 furnaces, 50 hp engine, 48″ x 8′ stroke, output 20 tons per week from 1 furnace, 30 tons per week from the other. Foundry closed this year, valued at £11,000.
1806	2 furnaces
1815	3 furnaces, 2 in blast, 32′ – 36′ high, 10′ – 11½′ diameter
1817	3 furnaces, all out of blast
1821	2 furnaces
1823	3 furnaces, approximately 50 tons/wk, (2475 tons per year)
1825	3 furnaces, 1 standing
1830	3 furnaces
1832	First furnace built at Blists Hill Site.
1840	Plan
1842	Madeley Wood Company had 4 blast engines of which 2 were at Blists Hill.

ILLUSTRATIONS REFERRED TO IN THE TEXT

John Sell Cotman (1782-1842)
Bedlam Furnace

Collection of Sir Edmund Bacon, Bt

Watercolour 9260 x 470 mm) Unsigned
Exhibited: Hull, 1938 (4); Arts Council, **English Watercolours from the Hickman Bacon** collection, 1946 (25); Norwich, **English Watercolours**, (1955 (51); Manchester, Whitworth Art Gallery, **The Norwich School** 1961 (46); Manchester, 1968) (143), Tate Gallery 1973 (263).

Literature: A P Oppe, **The Water Colour Drawings of John Sell Cotman**, Studio Special Number, 1923, p.viii; S D Kitson, **Life of John Sell Cotman**, 1937, p.41, repr. no. 5; T D Klingender Art and the Industrial Revolution, 1947, pp. 80-1, 176 fig 14; D Clifford, **Watercolours of the Norwich School**, 1965, p.xii, repr. pl. 296; F D Klingender Art and the Industrial Revolution. 2nd Ed. (Revised Elton), 1968, pp 101 1, 201 repr. pl VI (Col).

Edward Dayes (1763-1804) (attributed to)
Untitled

Monochrome Wash Drawing, Indigo with Indian Ink size 383 x 246 mm

Collection of British Museum – Turner Bequest

(CCCLXXI–J). Listed under doubtful drawings and probably acquired by Turner

Philip James de Loutherbourg (1740-1812)
Fire Engine, Coalbrookdale

Collection of British Museum CCCLXXII–47

Pen & Ink Drawing, Coalbrookdale (79 x 121mm)
Literature: A J Finberg, A complete inventory of the Drawings in the Turner Bequest, 1909, II, pp 1223-5.

✳ **Philip James De Loutherbourg (1740-1812)**
Coalbrookdale by Night

Collection of Science Museum, London, purchased from Pictura Ltd 1952.

Oil on Canvas (680 x 1067mm)
Exhibited: RA 1801 (54, as **A View of Coalbrookdale by Night**), Tate Gallery (1973). Manchester, 1968 (32).
Literature: Klingender 1968. pp 85

Joseph Farington (1747-1821) (attributed to)
The Iron Bridge near Coalbrookdale

Collection of Ironbridge Gorge Museum Trust

Pencil (384 x 597 mm)
Literature: A Raistrick, Dynasty of Ironfounders, 1953, repr. f.p. 112
Exhibited: Manchester 1968 (160)

✳ **Paul Sandby Munn (1773-1845)**
Bedlam Furnace, Madeley Dale, Shropshire.

Collection of Mrs Judy Egerton

Watercolour (328 x 555mm) inscribed P S Munn 1803.
Exhibited: RA 1803 (625), Tate Gallery 1973 (270)
Literature: S D Kitson, **The Life of John Sell Cotman, 1937**

William Pickett (active 1792-1820) after Philip James De Loutherbourg 1740-1812
Iron Works, Coalbrookdale

Collection of Ironbridge Gorge Museum Trust

Aquatint, hand coloured (30.3 x 36.4cm) **From the Original Drawing by P J De Loutherbourg**, RA; Published by R Bowyer, Historic Gallery, Pall Mall, 1805.
Exhibited: Manchester 1968 (229)
Literature: Klingender 1947, p.77 repr. pl. III (Col); Klingender 1968, pp 99-100, 201 repr. pl. V (Col). Reproduced in 1805 in **The Romantic and Picturesque Scenery of England and Wales**, re-issued 1824.

Note It is hoped to enclose with this issue of the Journal (by courtesy of the Ironbridge Gorge Museum Trust) coloured reproductions of the pictures marked with an asterisk.

REFERENCES

1 Barrie Trinder. The Industrial Revolution in Shropshire (1973) pp 33-45.

2 SRO 271/1

3 SRO 1681/14
Trinder, op.cit. pp. 39-40, 404

4 John Randall. The History of Madeley (1880) pp.99-100

5 ex. inf. Ivor J. Brown

6 The Thomas Butler Journal, Alan Birch, ed. The Midlands Iron Industry during the Napoleonic Wars, Edgar Allen News, Aug/Sept 1952.

7 Kidderminster Public Library, Stour Works Accounts.

8 British Museum Map Kxxxvi. 16.1

9 SRO 1987

10 Trinder, op.cit. pp.69

11 Friends House Library, Norris Collection. Vol. V.

12 J Randall, op.cit. pp 102, 174

13 SRO D876. Madeley Wood Company Annual Statements

14 Ibid. End papers

15 Report of Select Committee of the House of Commons on the Application of Iron to Railway Structures, 1849.

16 IGMT photograph

17 SRO 1987, SRO 245/140, SRO MS 335

18 Staffs RO D876/155

19 H Scrivenor. The History of the Iron Trade. (ed.1967) pp 95-97.

20 SRO 1781/6/28
B & W Colln. MII

21 Thomas Butler, op.cit.

22 M Elsas, Iron in the Making (1960) pp 3. B & W Colln. MII.

23 J Randall, op.cit. pp 178

24 J Watt – W Reynolds 3rd Jan. 1781. Institution of Mechanical Engineers.

25 W Reynolds & Co Boulton & Watt, 26.8.1796.
B & W Colln. Box 3 'R'

26 M J T Lewis, Early Wooden Railways (1970) pp 261-3 293

27 B Trinder, op.cit. pp.91-96.

Acknowledgements

I would like to thank the many people associated with the Ironbridge Gorge Museum who made this paper possible. In particular the Honorary Historian to the Museum Trust, Mr Barrie Trinder for his great assistance in carrying out historical research. Others are too numerous to mention but include the many experts who have advised, those who have re-built, those who have measured and drawn and not least the many who have dug. Thanks in particular are due to the Department of the Environment (Ancient Monuments) and the Manpower Services Commission.

The 1772 plan is reproduced by courtesy of the British Museum as are the Dayes and de Loutherbourg sketches, the oil painting by John Sell Cotman is reproduced by courtesy of Sir Edmund Bacon Bt and the Courtaulds Institute of Art, Coalbrookdale by Night by courtesy of the Director of the Science Museum. Mrs Judy Egerton has allowed her picture of Bedlam Furnace to be used. All other illustrations and plans are in the possession either of the Ironbridge Gorge Museum Trust or the author.

The Parker Brothers, Black Country Ironmasters

L B Hunt

Among the several ironmasters who moved from the Coalbrookdale area in the latter half of the eighteenth century to establish the iron and coal industry of the Black Country were five brothers named Parker, all Quakers, and grandsons of Esther Darby, the sister of Abraham Darby I.

Very little appears to be on record concerning these pioneers, but there has recently come into my hands a number of their family documents, passed down over the years to my wife and my brother-in-law, the Rev J A Bickerstaff of Brighton, who are among their descendants. These have now been handed over to the Ironbridge Gorge Museum, but a summary of their contents may help to place this family and their activities on record for historians of metallurgy.

Abraham Darby's sister Esther (1680-1728) married Anthony Parker (1662-1740), described as a nailer of Wassall, Hagley, in 1706 and lived at Madeley Lodge, overlooking the Severn Gorge which their great nephew was to bridge in 1779. They had six children, Esther, born 1707, who married Richard Phillips, a Quaker ironmaster from Welshpool, Anthony, born 1709, who married Hannah Pritchard – and whose five sons are the main subject of this note, together with one of his daughters, her husband and son – Ann, born 1715, who married one of the Cranage brothers, the patentees in 1766 of a process for making wrought iron from pig iron with coke in a reverberatory furnace, and three others.

Little is known of Anthony Parker's life and work. He had a business of some kind in Madeley and died in 1766, two years after the death of his wife, leaving eight children, three of them girls, the oldest boy being 26 and the youngest only four years old. The younger children were then brought up by their grandmother, Mrs Pritchard, at Coalbrookdale. The older sons joined their Darby cousins, Abraham III and Samuel, in the Coalbrookdale works, as did the younger ones on reaching the age of 14. They were George (1740-1814), Richard (1743-1812), John (1748-1807), Abraham (1755-1830) and Benjamin (1762-1816), and they learnt the ironmaking and ironfounding trade at Coalbrookdale until the death of their grandmother in 1783.

At this time, George being 40 and and the young Benjamin now 21, they all migrated to Tipton in Staffordshire where ironstone, coal and limestone were all easily obtainable, and formed themselves into a company, George Parker and Co. A small blast furnace was erected on land leased from Lord Dudley on the canal bank a little to the north-west of the old established Coneygre furnace. They had very little in the way of financial resources, but that they were quite soon successful in their operations is clear from the fact that they rapidly expanded by building a second furnace at Tipton and another at Apedale near Newcastle-under-Lyme on land leased from Sir Nigel Gresley. The two plants were conveniently linked by the new canal, and in 1790 a deed, still in existence, records the leasing by Josiah Wedgwood to the five Parker brothers of "a piece or parcel of land adjoining to the Navigation from the Trent to the Mersey . . . as a Wharf for the loading and unloading of Limestone and Pig Iron" at an annual rental of £11.

By 1798 the Tipton plant is described as comprising two furnaces producing 20 to 25 tons of pig iron a week, one rolling and slitting mill and three forge hammers. As they prospered, the brothers also acquired land and mines at Oldbury and elsewhere and in fact became very wealthy as iron and coal masters on quite a large scale.
One of their sisters, another Esther, had secretly married, against her parents wishes, Levi Parker, a neighbour from Madeley but not a relative, in Bristol in 1778, and although his radical views displeased his brothers-in-law during the French Revolution he was offered the position of manager of the Apedale works in succession to Abraham who had returned to Tipton after his marriage in 1790. Lengthy correspondence took place between Benjamin at Tipton and Levi at Apedale concerning the management of the plant and of farmlands which the Parkers, like their Darby cousins, had begun to acquire. Levi was also a neighbour and friend of Josiah Wedgwood.

Esther and Levi had four children, and the youngest of these, George, born in 1792, became the favourite of his uncle George and when grown up was employed in the Tipton works, becoming the joint manager in 1816 by which time his uncles had retired or died. His fellow manager was his cousin, also George Parker, the son of Abraham, born in 1798. These two carried on the business until 1824 when Levi's son George withdrew from the partnership on his marriage and after some disagreement over the management of the business.

This explains the reference in Mr W K V Gales booklet 'The Coneygre Story', where he writes (page 11)

> "Parker worked the Coneygre plant on his own account, for several records show that while George Parker and Company operated the Tipton Furnaces, George Parker alone had Coneygre"

They were two different George Parkers, one the son of one of the original founders of the company and the other the son of their sister Esther and Levi Parker from whom the documents have passed down through the family.

The Apedale plant was sold in 1839; it is not recorded when the Tipton works closed, but it must have been at approximately the same time. It was certainly still in operation in 1829, while George Parker (Abraham's son) died in 1848. The other George Parker's lease of the Coneygre furnace, according to Mr Gale, also came to an end before 1839, although he lived on until 1876. No more Parkers entered the iron industry.

The Saltford Brass Annealing Furnace

Joan Day

The brass works established at Baptist Mills in Bristol about 1702 by Abraham Darby and three partners quickly achieved some measure of commercial success and in a few years was expanding. In the last decade of the seventeenth century, Bristol had been the scene of technical innovation in the smelting of copper. Darby had come to Bristol in 1699, following a Birmingham apprenticeship to set up his own business in his trade as a maker of maltmills, but very soon became involved in the new brass-making enterprise which appears to have developed partly because of surpluses in the local production of refined copper.[1]

With the expansion of the non-ferrous industries which took place in Bristol from the first decade of the eighteenth century, brass metal continued to be made at the original premises at Baptist Mills, but additional water-mill sites were needed by the company to operate water-powered hammers. These were used for *beating* cast slabs of the metal to form brass sheet in the early years of the industry, but this same *battery* method of production was to survive for just over two centuries in the local manufacture of utensils made from brass. In the first thirty years of the century leases were taken for sites of these battery mills, as they were called, at Keynsham, Saltford, Woollard and Weston near Bath, (a list that was later to be extended). Land for the Saltford battery mill was leased in 1721,[2] on a site that had been occupied previously by a long-established fulling mill.

Situated on the River Avon, on the upper of two weirs in the parish of Saltford, the Old Brass Mills at ST 687670 can be approached by The Shallows, a river-side road which used to be called Brass Mill Lane. The remaining mill fabric consists of a much-altered and partly demolished structure of local limestone, with a complicated pantiled roof which, with study, may well yield indications of the original core of the building.[3] The structure incorporates remains of annealing furnaces, one almost complete, which endow the building with a distinctive character but, apart from remaining waterwheels, there is little surviving evidence of the plant employed for brassmaking over its 200 years of existence.

During the first half of the century the company adopted the use of water-powered rolling mills to produce its brass sheet, thus modernising its production. The rolling of copper sheet had been introduced by John Coster at Swinford, some two miles downstream, when he leased the mill there in 1709. Coster had previously been associated with William Dockwra in establishing the copper-smelting works at Upper Redbrook in 1691.[4] By 1697 Dockwra was reported at his Esher mill in Surrey, to be rolling copper instead of using the battery process for flattening ingots, an innovation for the industry.[5]

Later, at Saltford, after the introduction of water-powered rolling the battery hammers still remained for the manufacture of hollow-ware vessels. This operation was never modernised and it lingered into the twentieth century. When a valuation was made of company property in 1830, Saltford Mill then contained a rolling mill powered by two waterwheels (the upper and lower rolls of the mill would have been driven by separate wheels). Two further waterwheels provided power for two battery mills, each wheel driving three hammers. A surveyor's report of 1855 described Saltford Mill as very old and in a decaying state, but it is quite clear from a Sales Catalogue of 1862 that, by then, little had altered.[6] An additional iron waterwheel had been installed for a grinding wheel, but the four wheels mentioned earlier for driving the rolling and battery mills still remained in place, described as 15ft by 3ft 6 in, complete with wooden shafts and gearing. This same catalogue also mentions four annealing ovens, an integral part of the premises which, undoubtedly, had been in existence from the previous century.

Such annealing ovens, (or furnaces, as they are more correctly called) were standard equipment at the local brass mill where frequent annealing was required at all stages of the work. The severe mechanical treatment of rolling and battery production caused distortion in the crystal structure, making the brass hard and brittle. This could only be rectified by a process of heat treatment which softened, or annealed, the metal and enabled work to proceed to a further stage. In the few early descriptions of the techniques of brass production annealing methods are very rarely mentioned. From eighteenth-century illustrations of continental brassworks, it can be inferred that the usual practice on the Continent was to employ a structure rather similar to a blacksmith's hearth. An open fire, presumably of charcoal, is usually portrayed at waist height with pairs of large water-powered bellows providing the draught.[7]

Andrew Ure, writing in the 1830s, implies that, by then, a type of large enclosed furnace was in fairly general use both in this country and on the Continent.[8] The internal dimensions he refers to vary, with lengths up to as much as 32ft x 6ft, according to the goods being annealed. This size of furnace was heated by two fireboxes accommodated on either side of the whole length of the furnace interior. The type of fuel is not mentioned but, presumably, was not coal as furnace gases were not separated from the load being annealed. The wares were mounted on carriages which ran on rails into the furnace and, once in place, the furnace door was closed by a lever or chain balanced by a counterweight. Ure also described two specific annealing furnaces at the Hegermuhl brassworks, near Potsdam, which differed in some details but made use of similar principles.

The furnaces used in the Bristol area were developed by the local industry during the eighteenth century and, until recently had not been thought to appear elsewhere, (although they do display some of the features described much later by Ure in the 1830s). However, recent excavation of the brass battery works at Holywell in Flintshire has revealed some remains at ground level which suggest structures similar to the annealing ovens of Bristol origin. (It is worth noting that a site at Holywell was first leased in 1758, and a brass works built by John Champion, who was closely connected with the Bristol industry). But the Holywell remains are minimal; in consequence, the almost complete furnace remaining at Saltford, together with two outer shells of similar structures at Kelston Brass Mills, about a mile distant, are believed to be the only significant remains of this type of furnace in existence anywhere. Coal-fired, and dating from the eighteenth century, they have a place in the development of coal technology in this country.

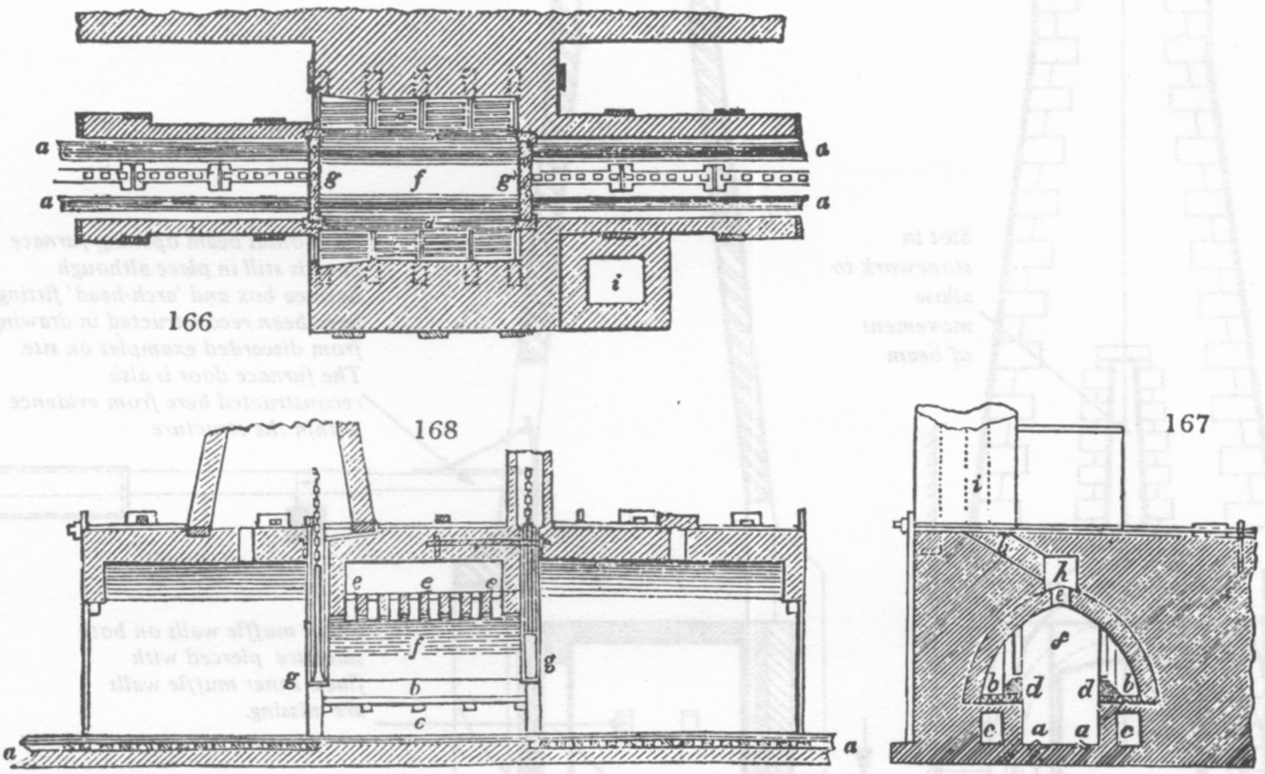


Fig. 166. shows the ground plan of the furnace and its railway; *fig. 167.* the cross section; and *fig. 168.* the section lengthwise; *a a,* the iron way bars or rails upon the floor of the foundry, for enabling the wheels of the waggon-frame to move readily backwards and forwards; *b b,* the two grates; *c c,* the ash pits; *d d,* the fire beams; *e e e,* vents in the roof of the hot chamber *f; g g,* two plates for shutting the hot chamber; *h,* the flue; *i,* the chimney.

Fig. 1 *From Andrew Ure's Dictionary of Arts Manufactures and Mines*

Brass-plate rolling – At Hegermuhl there are two re-heating or annealing furnaces, one larger, 18 feet long, and another smaller 8½; the hot chamber is separated from the fire place by iron beams, in such a way that the brass castings are played upon by the flames on both their sides. After each passage through the laminating press (rolls) they are heated anew, then cooled and laminated afresh, till they have reached the proper length. The plates are besmeared with grease before rolling.

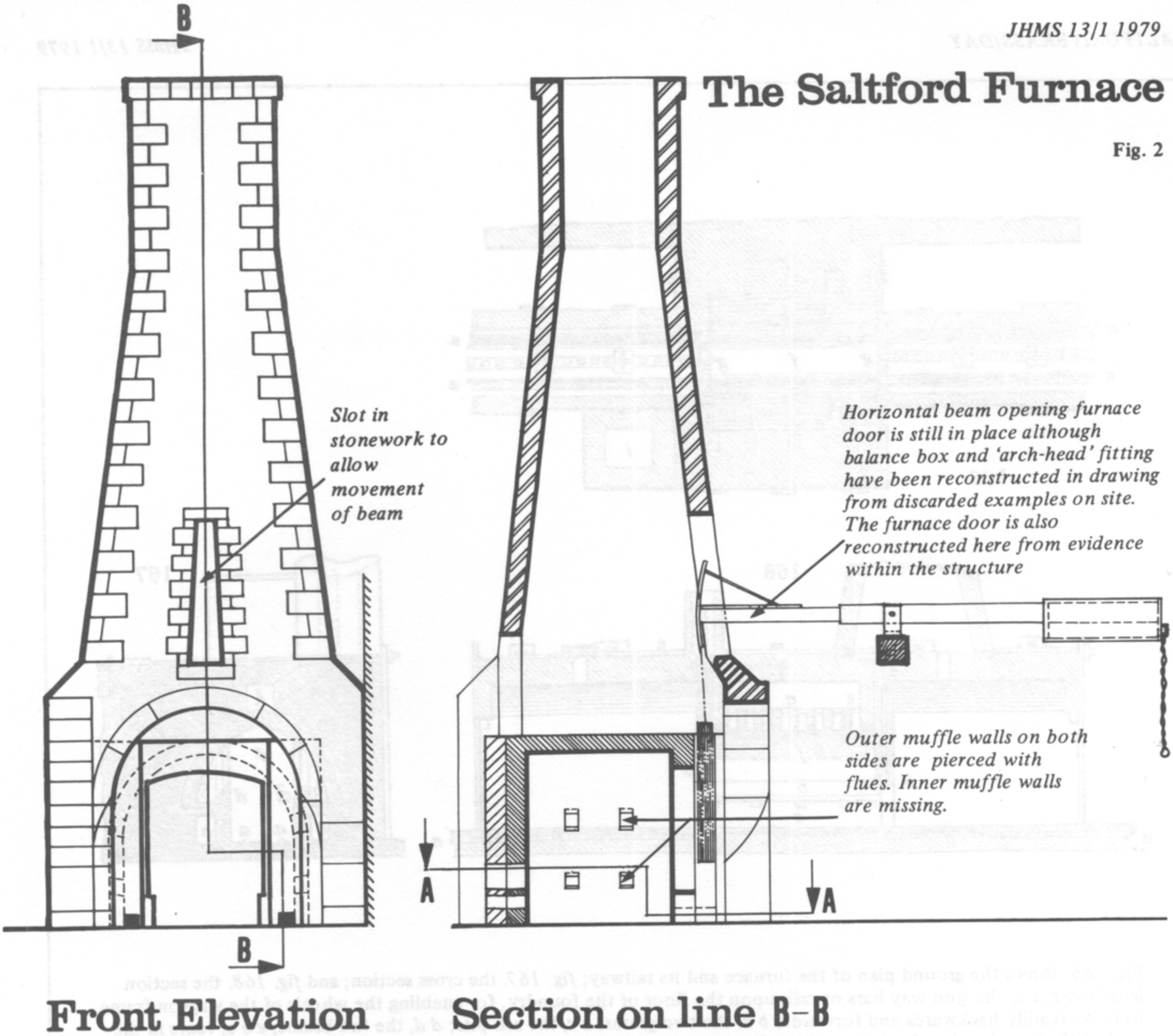
Prior to the establishment of the Bristol brass industry, coal had already been used there successfully for metallurgical purposes. The smelting of lead in coal-fired reverberatory furnaces had been achieved in the 1670s and further work had lead to the smelting of copper in similar structures by the last decade in the century.[9] By 1710, there is firm evidence that coal was fuel being used in the making of brass metal.[10]

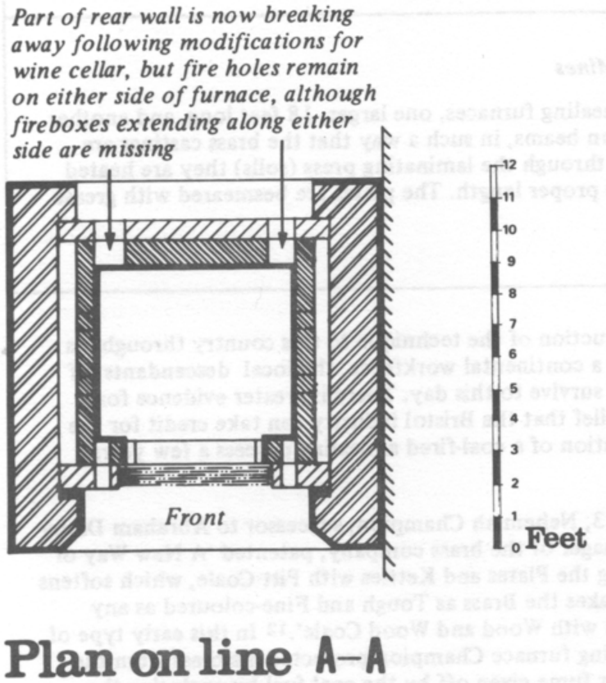
In previous accounts it has been assumed that this was also an innovationary technique for which Abraham Darby was responsible.[11] More recent research, however, has revealed the use of coal fuel for brass-making, at Aachen on the Continent,[11a] from the previous century. Possibly, Darby may have been responsible for the successful introduction of the technique to this country through his use of a continental workforce, the local descendants of which survive to this day. There is greater evidence for the belief that the Bristol industry can take credit for the innovation of a coal-fired annealing process a few years later.

In 1723, Nehemiah Champion, successor to Abraham Darby as manager of the brass company, patented 'A New Way of Nealing the Plates and Kettles with Pitt Coale, which softens and makes the Brass as Tough and Fine-coloured as any Nealed with Wood and Wood Coale'.[12] In this early type of annealing furnace Champion protected his brass from the sulphur fume given off by the coal fuel by enclosing the

The Saltford Furnace

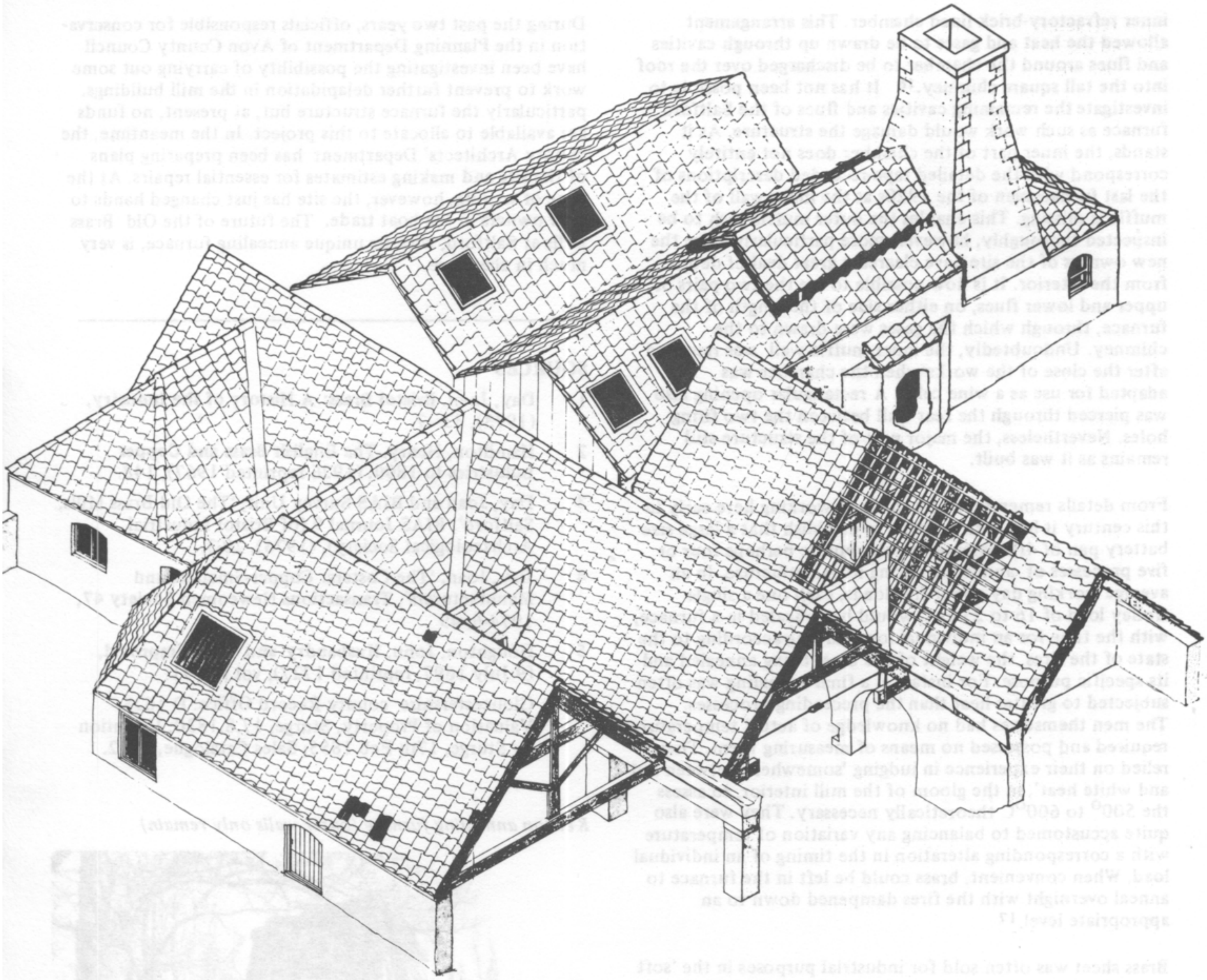
Fig. 2





wares in wheeled cast-iron containers which were then completely sealed with clay. The furnace interior was 5ft square with a 4ft high arched roof and 1½ft thick side walls. The fire entered the furnace through apertures in these side walls and was drawn up, and reverberated from the arched roof on to the protected boxes below.[13] The oven door could be raised and lowered by a chain, which suggests a similar arrangement to the horizontal balance beam used in the later development. (see Fig. 2) This early coal-fired annealing furnace was, therefore, a type of reverberatory furnace (in which there had been much previous local innovation in the smelting of non-ferrous metals) but the presence of coal gases in the furnace interior made it necessary for the annealed wares to be very well protected.

Between 1764-8, when Nehemiah Champion's son William built his own company's new battery mill at Kelston on the next weir downstream to Saltford mill, a more sophisticated type of coal-fired annealing furnace appeared, two shells of which remain. In this structure the furnace gases were kept in quite separate outer cavities, in the side-walls along the length and above the roof of the furnace. The inner surface of the interior was kept well smeared with clay by the furnaceman to prevent sulphur fume from penetrating to spoil the brass. Thus, the work



drawing by Megan Thomas

The Old Brass Mills, Saltford as they are today

being annealed so longer required the protection of a sealed container. The load could simply be stacked in the oven, on trolleys to facilitate handling, and it was these trolleys, or dilleys, which were manoevred into place on a railed track by means of a revolving turntable.[14]

William Champion himself may well have been responsible for this development in furnace construction, which today would be called a 'muffle'. furnace, with its heating cavities surrounding, but separate from, the interior. In Champion's patent No 867, enrolled in 1767, he included with other processes, a method 'for Manufacturing Brass into Brass Wire by Stone or Pitt Coal instead of Wood now used'. As brass was nearly always worked cold during the eighteenth century, whether to roll sheet, form hollow-ware, or draw narrow strip into wire, it is difficult to imagine any other a purpose for heat treatment or for the above patent, other than for the annealing process. Members of the Champion family were past masters at obtaining protection for their inventions by giving deliberately vague or misleading descriptions of processes in their patent specifications.

The building of Kelston Mills was one of the final phases of expansion by William Champion before being declared bankrupt in 1769. All the premises of his company were subsequently taken over by the old Bristol brass company, who used them, but far less extensively, before gradual disposal of the properties. The basic design of the remaining coal-fired annealing furnace at Saltford is the same in overall measurement apart from a few minor details, suggesting that it was probably copied from those at Kelston by the old Bristol company.[15]

At the front of the furnace an archway at the base of the tapering squared stack gives access to the interior. (see Fig.2) A heavy fire-brick door would have been mounted between the arch and the inner chamber and raised by a horizontal timber beam. This was counter-balanced at the opposite end so that the door could be opened easily by lowering a chain, while the movement of the pivotted beam was accommodated by a vertical slit in the stonework of the stack. At the opposite end of the furnace another higher arch housed two fireholes which extended along either side of the whole length of the inner refractory-brick lined chamber. This arrangement allowed the heat and gases to be drawn up through cavities and flues around the chamber to be discharged over the roof into the tall square chimney.[16] It has not been possible to investigate the remaining cavities and flues of the Saltford furnace as such work would damage the structure. As it stands, the inner part of the chamber does not entirely correspond with the detailed tape-recorded descriptions of the last furnacemen of the 1920s as the inner wall of the muffle is missing. This enables the outer muffle arch to be inspected thoroughly, however, more particularly since the new owners of the site have cleared a great deal of debris from the interior. It is now possible to see the two pairs of upper and lower flues, on either side of the length of the furnace, through which the gases were drawn to the chimney. Undoubtedly, the inner muffle wall was removed after the close of the works when the chamber was adapted for use as a wine cellar A rectangular opening also was pierced through the rear wall between the two firing holes. Nevertheless, the major part of the structure still remains as it was built.

From details remembered by the men working here early in this century it has been possible to establish that a large size battery pan of 4ft diameter would require perhaps four or five processes of annealing during its manufacture. In an average working day about five loads, each one a single trolley load of 16 to 25 cwt, would be annealed in a furnace, with the time for an individual load varying according to the state of the fires, the weight of the brass being annealed and its specific purpose. For instance, a final annealing was often subjected to greater heat than the preceeding processes. The men themselves had no knowledge of actual temperatures required and possessed no means of measuring them. They relied on their experience in judging 'somewhere between red and white heat', in the gloom of the mill interior, to assess the 500° to 600°C theoretically necessary. They were also quite accustomed to balancing any variation of temperature with a corresponding alteration in the timing of an individual load. When convenient, brass could be left in the furnace to anneal overnight with the fires dampened down to an appropriate level.[17]

Brass sheet was often sold for industrial purposes in the 'soft dark' state, as it emerged from the final annealing. If a hard bright finish was required the sheet was pickled by immersion in dilute sulphuric acid. After a thorough washing in clean running water and a careful drying in bran, the sheet received a final rolling in the Saltford finishing rolls.

The men had seen many alterations to the equipment over the years and could tell of others before their time. For instance, of the completely unsuccessful attempt to modernise one of the sets of battery hammers in the late nineteenth century by replacing timber with wrought and cast iron.[18] The project was abandoned eventually but these and other modifications left their mark on the mill buildings and made interpretation difficult. One set of older hammers continued working until 1908 but the rolling mill did not come to a halt until 1925. When the mill finally closed the remaining annealing furnace was still capable of good service.

After the brass mills ceased to work a bungalow was built on part of the site and the old buildings were adapted for various purposes. One section was used as a squash court, the annealing furnace was modified, as mentioned, for the storage of wine, whilst the large remaining waterwheel was employed to generate electricity. These alterations have created further difficulties in the interpretation of surviving structures. In more recent times the whole island site has been used for the building and storage of boats.

During the past two years, officials responsible for conservation in the Planning Department of Avon County Council have been investigating the possibility of carrying out some work to prevent further delapidation in the mill buildings, particularly the furnace structure but, at present, no funds are available to allocate to this project. In the meantime, the county Architects' Department has been preparing plans of the site and making estimates for essential repairs. At the time of writing, however, the site has just changed hands to new owners in the boat trade. The future of the Old Brass Mills at Saltford, with its unique annealing furnace, is very much in abeyance.

SOURCES

1 Day, Joan. **Bristol Brass: A History of the Industry,** (1973), 33–7.

2 Hamilton, Henry. **The English Brass and Copper Industries to 1800,** (1926 reprinted 1967), 148.

3 Day, Joan and BIAS Survey Unit, 'The Old Brass Mills, Saltford', **BIAS Journal 9** (of Bristol Industrial Archaeological Society), (1976), 20-3.

4 Day, Joan. 'The Costers: Copper-Smelters and Manufacturers', **Transactions Newcomen Society 47,** 1974-6, 49

5 Houghton, John. **Husbandry and Trade Improv'd,** (9 July 1697, reprinted 1727), vol II, 191.

6 Gloucestershire county Record Office. D 1628, Valuation of Property, Sturge, 17.8.1830; Valuation by Sturge, 17th Feb 1855; Sales Catalogue, 1862.

Kelston annealing furnace (outer walls only remain)

photograph by Roy Day

7 Van Natrus, L Pouy, Jand Van Vuuren, C. Groot Volkomen Moolenboek, Amsterdam (1734, reprinted 1969) Pt 2, Plate VII, Kooper-Moolen, (By courtesy of Martin Watts);
Galon, J. L'Art de convertir le Cuivre rouge en Laiton ou Cuivre jaune, (1764).
Diderot, D. Pictorial Encyclopedia of Trades and Industry, (1763 Paris, reprinted 1959 New York) Vol I, Plate 145.

8 Ure, Andrew. A Dictionary of Arts, Manufactures and Mines, (1839), 166 & 168.

9 Jenkins , Rhys. 'Copper Works at Redbrook and Bristol', Transactions Bristol & Gloucestershire Archaeological Society 63, (1945), 145-54; 'Copper Smelting in England: Revival at the end of the Seventeenth Century', Transactions Newcomen Society 24, (1943–4), 73-80.

10 Journal of the House of Commons, (1712), 161.

11 Mott, R A. MS 'Revolution in Iron', Ch 14, 192 (I am grateful to Dr Mott for allowing me to read this chapter, unpublished at the time of writing); 'Abraham Darby (I and II) and the Coal-Iron Industry', Transactions Newcomen Society, 31, (1967), 49-57; The Triumphs of Coke, (1965), 16.

11a Weigels,Christoph Abbildung der Haupt-stande (1698) by courtesy of John Morton, who kindly drew this to my attention, from research arising from his forthcoming thesis at Birmingham University.

12 Patent Specification, No 454, (1723).

13 Swedenborg, E. De Cupro, (1734), 354; English Translation, Searle, A H. British Non-Ferrous Metals Research Association, Misc. Publication 333, p 343.

14 Day, Bristol Brass, 147–50 and 214.

15 ibid, 89-94.

16 ibid, 150, Additional details from notes and tape recordings of conversations between the author and Mr A E Shellard, Mr T G Shellard and Mr H Barnett, former employees at the mill.

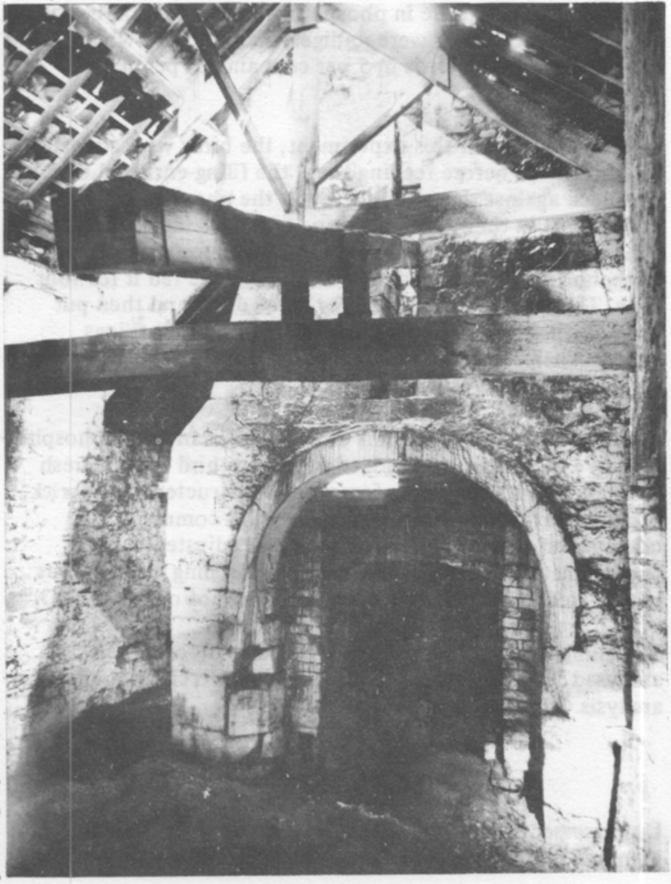
17 ibid.

18 de Soyres B, 'History and Particulars of the Brass Battery Process', Transactions Newcomen Society, 28, (1952) 131-5;

ACKNOWLEDGEMENTS

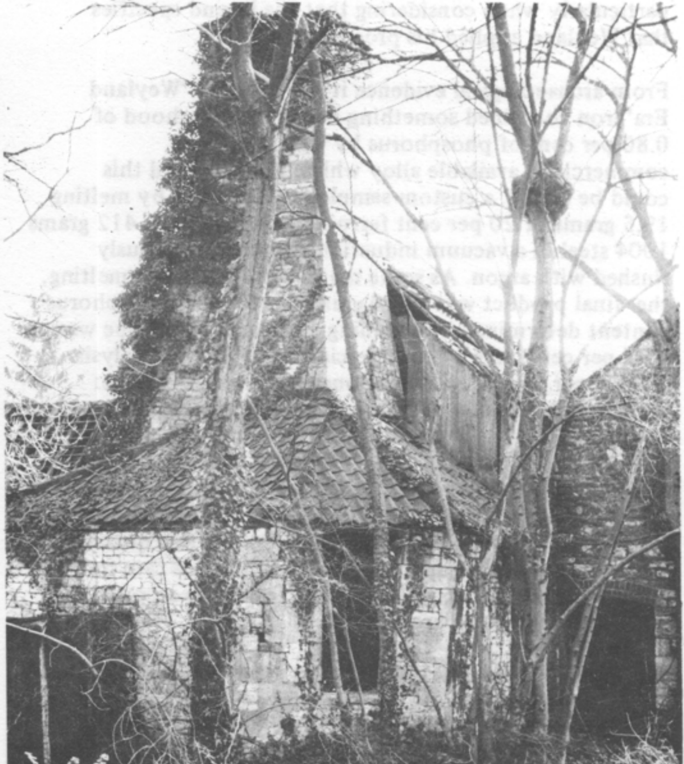
I am indebted to members of the survey unit of Bristol Industrial Archaeological Society who measured the Old Brass Mills site, to my husband Roy for measuring and drawing the annealing furnace and to Megan Thomas of Avon County Architects' Department for the three-dimensional drawings of the site. I must also thank the past and present owners of the mill for their co-operation in allowing access, and to the Conservation Group of Avon Planning Department and DoE Inspectorate of Ancient Monuments for their interest in the future of this site

The front arch of Saltford annealing furnace



photograph by George Watkins

Exterior of furnace at Saltford



photograph by Roy Day

Weyland the Smith: some findings

*Gregory Martin and Vernard Foley**

In an earlier issue of JHMS, it was proposed that some metallurgical truths might be concealed in the medieval German legend of Weyland the Smith. Readers will perhaps recall that Weyland is said to have produced superior swords by reducing ordinary weapons to filings, mixing these with meal, feeding certain domestic fowl cakes made of this meal, and then recovering the iron by incinerating the birds' droppings in his forge. The earlier discussion proposed two possibilities for a core of metallurgical truth in the legend. First, that the digestive biochemistry of the birds might remove some amount of phosphorus from the iron, phosphorus being especially involved in eggshell formation. There is evidence to indicate that excessive phosphorus characterized ore bodies which were likely used in the region where the Weyland legend circulated, at the time of its origin. As a second possibility it was suggested that the high ammonia content of avian dung might liberate sufficient nitrogen in the incineration process to nitride the iron. This might increase its servicability for weapons use, independently of phosphorus removal.

At the time of previous publication, data had been accumulated which seemed tentatively to support the phosphorus removal hypothesis. Attempts to reproduce these results made it seem likely, however that the investigators had been initially led astray by surface contamination of the filings, owing to incomplete cleaning. At the present stage of investigation it appears that phosphorus removal does not occur. Nitriding, however, has been achieved in significant amounts, particularly when considering that the legend specifies that Weyland applied his process repeatedly.

From archaeological evidence it appears that 'Weyland Era' iron contained something in the neighborhood of 0.80 per cent of phosphorus by weight. As no commercially available alloy which aproximated this could be found, a custom sample was prepared by melting 19.5 grams of 20 per cent ferro-phosphorus, with 412 grams 1004 steel in a vacuum induction furnace continously flushed with argon. As some metal was lost during melting, the final product was a 250 gram ingot whose phosphorus content determined by scanning electron microprobe was 0.72 per cent, and by commercial wet chemical analysis at 1.07 per cent. Other components of the alloy were: carbon, 0.04; silicon, 0.007; manganese, 0.3; and silicon, 0.006.

This ingot was reduced to filings using ten-inch, double-cut, mill bastard hand files. By vigorous filing it was possible to remove about 14 grams of metal in a quarter hour. For someone capable of maintaining this rate for an eight hour day, about 450 grams, or about a pound of metal, could thus be processed.

Chickens were used as the test fowl. They are physiologically similar to the ducks and geese which are specified in some versions of the legend, and were more available.

Initial attempts to feed the chickens involved the preparation of meal cakes composed of whole wheat flour, water, and 5 per cent iron filings by weight, cooked in polyunsaturated cooking oil. The chickens would not touch them. After attempting several other recipes with unvarying results, the experimenters fell back upon a dry mixture of filings and corn meal, the birds' customary diet. This was consumed without any noticeable repugnance. Filing proportions up to 20 per cent were eaten, but the bulk of the experiments were conducted with a 5 per cent diet. The birds ate this as they did their normal feed.

Iron recovery was effected by suspending a cardboard sheet, covered with plastic film beneath the birds' cages. Separation of the filings and the dung was done by flushing the latter with water, while collecting the iron using a magnet applied to the outside of the beaker. Further application of ultrasonic cleaning was required to rid the filings of visible manure traces. Thus cleansed they were mounted and inspected by the scanning electron microprobe. This revealed the presence of calcium, sulfur and phosphorus to the amount of several percent. All three are found in chicken manure. Accordingly the filings were further cleaned by soaking in a 2.9m solution of potassium carbonate for three hours.

To test for phosphorus removal from the center of the filings, a sample of these was mounted in bakelite, metallurgically polished, and scanned using an SEM Microprobe. No difference in phosphorus content could be found between this group and the undigested filings.

To test for superficial phosphorus removal a small pile of filings was placed atop a graphite block and scanned. The microprobe penetration ranged between one and two microns. No difference in phosphorus content could be found among samples which were undigested, and those which had passed through the birds in 5 per cent and 20 per cent concentrations.

In the initial run of this experiment, the birds were starved for three days before feeding them the filing-enriched diet. To check against the possibility that the phosphorus enrichment in their ordinary food was masking the effect sought, the experiment was repeated. A special diet free of phosphorus was prepared, and the birds were fed it for four days. They were next starved for three days, and then put back on the no-phosphorus diet, with 5 per cent filings added. Analysis of the filings recovered from this experiment yielded the same results as before.

To test for nitriding, 7 grams of filings used in the dephosphorization experiment were mixed with one-third liter of fresh chicken manure. A simple forge was constructed of firebrick, supplied with an air blast and fueled with commercial charcoal briquets. The temperature was adjusted to approximately 1,000°C, and the manure-filing mixture was incinerated in small batches for an average of one-half hour.

The filings were recovered and cleaned as before, then analysed for nitrogen content using commercial wet chemical analysis. The results are as follows:

Unprocessed filings: 0.019% Nitrogen, by weight
Manured and incinerated filings: 0.13% Nitrogen, by weight

Nitriding was found to some degree on 60 per cent of the filings, measured by volume. The rate of diffusion of the nitriding was found to be comparable to modern processes. Although at this time the effect on steel of nitriding with chicken manure is not completely known, two mechanisms suggest themselves. First, by dispersing the nitrides throughout the sword the entire sword could be strengthened. This assumes the nitrided filings composed the whole of the blade. Second, by nitriding only the surface of the sword a very hard cutting edge and a tough core could be produced. This could be done by heating a finished sword in a forge fired by charcoal and manure.

In conclusion there appears to be no experimental confirmation for the supposition that digestive removal of phosphorus from iron filings by the domestic chicken occurred in Weyland's time. However, it does appear that prehistoric Northern European smiths may have evolved a nitriding process of essentially modern effectiveness.

FOOTNOTE

[1] Dennis Willen, Werner Soedel, and Vernard Foley, 'The Story of Weyland the Smith: an ancient Thomas-Gilchrist Process?' **Journal of the Historical Metallurgy Society**, 10-2, 1976, 84-86.

ACKNOWLEDGEMENTS

The foregoing would have been impossible without the support and assistance of many people. The list includes Jim Cordea of Armco Steel and the following, who were all at the time associated with Purdue University: James R Carson, Professor of Animal Sciences; Tilford R Cline, Professor of Animal Sciences; William R Featherstone, Professor of Animal Sciences; Lois Magner, Associate Professor of History; H R Harrison, Central Materials Processing Facility, School of Materials Engineering; David McCabe, Robert Staley and Arnold Wilson, technical staff, School of Materials Engineering; Jack Chasteen and P V L N Sarma, Instructors of Materials Engineering; Paul B Eaton, Professor of Materials Engineering; Robert H Spitzer, Professor of Materials Engineering; Peter G Winchell, Professor of Materials Engineering; Gerald L Liedl, Assistant Head and Professor, Materials Engineering; Thomas H Heim, Poultry Farm Manager, Animal Sciences Research Farm; Ky-Han Kim, Professor of Biochemistry; Henry O Meyer, Professor of Geosciences; Herbert E Parker, Assistant Head Professor of Biochemistry; Oliver C Sabie, undergraduate, Department of Biochemistry; Werner Soedel, Professor of Mechanical Engineering; Dennis Willen, undergraduate, Department of Physics. If our discussion has any merits, much of the credit must go to these people. Shortcomings the authors reserve for themselves.

*Purdue University, Indiana, USA

A note on Cunsey Furnace Hearth

Among documents in the Hart Jackson papers[1] is a small notebook dating from 1716, apparently used by William Rawlinson of Backbarrow ironworks as a receipt book. One leaf contains the following note:

> E. H.   Cunsey
> Harth
> The bottom stone to have a
> small discent both towards
> the wind wall and the Timpe.
> The Twear to be 12 inches
> from the bottom and 9 inches
> from the back wall.
> The Backe wall 16 inches [wide];
> The Timpe 17 inches wide.
> The Harth 5 foot 3 inches high.
> The Blast to blow on
> the wind wall betwixt
> 4 & 5 inches below the Twire.

The initials E. H. presumably relate to Edward Hall, partner in the Cunsey furnace, and it is somewhat surprising to find this note among papers belonging to the proprietors of the rival furnace at Backbarrow.

The hearth may be compared with that at Pontypool furnace in 1704.[2] The hearth at Cunsey was both narrower (by 2 to 3 inches) and higher (9 inches). Though the casting aperture will have been narrower than at Pontypool, it probably did not greatly differ in height, since the tuyere was set only a half inch higher. On the other hand, nearly the whole of the increase in height occurs in the section of the hearth between tuyere and boshes. Possibly the most interesting statement is that giving the angle of depression of the blast – around 15°.

Cunsey furnace was probably roughly midway in size between Mearheath (output averaging over 20 tons per week in 1693/4[3]) in which the Cheshire partnership had an interest, and their Duddon furnace of 1737 (output 10 tons per week in 1750/1).[4] The 1717 list of furnaces gives the annual output of Cunsey as 500 tons, as against 600 tons for Mearheath and 400 for Pontypool.[5]

London, 31.8.78.   Brian Awty

REFERENCES

1 Lancashire Record Office, DDHJ (uncalendared). Messrs Hart Jackson and Sons have kindly given their consent for the publication of this extract.

2 H R Schubert, **History of the British iron and steel industry** (London, 1957), Appendix XVI.

3 Calculation from notes on the Foley MSS, kindly lent by Professor B L C Johnson.

4 Lancashire Record Office, DDX 192/1.

5 E W Hulme, 'Statistical history of the iron trade of England and Wales, 1717-1750' in **Transactions of the Newcomen Society**, 1928/9, Vol. 9, pp 21-22.

Notes on current excavations 1

ROCKLEY FURNACE – SE/338021

The charcoal blast furnace at Rockley, South Yorkshire, is first referred to in 1652, when land for its construction was leased by Lionel Copley, of Rotherham. Iron had previously been smelted in the locality by the bloomery process, as shown by excavations at Rockley Smithies in 1964-6. The furnace passed to the Spencer partnership by the end of the seventeenth century; it formed part of a group of furnaces and forges exploiting the ore and timber resources of the Tankersley outcrop.

Firm evidence for the use of the furnace is lacking after about 1740, although there is an unattributed reference, in Andrews' **History of Wortley Forge,** to the smelting of iron with coke at Rockley in 1799.

The furnace which survives retains many features typical of seventeenth-century practice, notably the square plan of the shaft. However, the frequent rebuilding indicated by accounts for other furnaces of the time suggests that much of the masonry will date from years later than 1652. The site of the furnace and the nearby Newcomen engine house are owned by the Sheffield Trades Historical Society.

What was not clear before this year's excavation was the layout and character of the bellows, waterwheel and casting floor. Thus plans to re-site the security fence were hindered by the danger that working levels might be damaged by post-setting, and excavation took place so that a realistic area might be enclosed in the future. The work was carried out under the auspices of the Sheffield Trades Historical Society, and the South Yorkshire Trades Historical Trust.

The Bellows and Wheel

Excavation showed that the bellows were placed on the north site of the Furnace, mounted in a building whose floor lay 1 metre lower than that of the furnace, and to which access was gained by a flight of stone steps. In this floor were slots for the beams supporting both the bellows and the western bearing of the shaft. Mid-seventeenth-century pottery fragments were found in the working levels of the floor. The wheel pit was lined with stone, and was dug to a level two metres below the bellows floor. It was remarkably narrow, varying between 40 and 50 cm, and had contained a timber water wheel 30 cm wide. Fragments of this lay on the stone floor of the pit, but had been so crushed by rubble that the diameter could not be established. The wood had rotted to a degree that must suggest a period when the water-table had retreated below the level of the wheel, perhaps due to drainage of nearby mine workings. Thus recovery and conservation were not feasible, nor was it possible securely to determine the configuration of the wheel. It appeared most likely, however, that it had been over-shot in form.

The wheel pit was excavated to its northern extent, and its exit recorded. However it was not possible to work at the southern end on this occasion. A particular problem was the discovery of a channel entering the pit at a low level towards the southern end of the eastern wall. This remains to be explored.

The Casting Floor

Although the furnace appears in the Spencer accounts as a producer of pig iron, no trace of pig-beds survived on the central and southern parts of the casting floor. The casting level appeared to have been obliterated by the excavation of a pit, two metres in diameter, with a stepped stone lining of the highest quality. The bottom of the pit lay three metres below the floor level in the furnace arch; it seemed likely that much of the upper stonework had been robbed, leaving a circular depression around the surviving courses. The pit had no constructed floor, natural shale having been excavated to form a level bottom. To the south west, the upper masonry was interrupted to provide an access passage. A slot had been cut in the floor, but any beam had been removed. Stone revetting walls had been robbed, leaving sharply-defined sides. A trench running south east from this passage remains to be excavated.

The most likely explanation of the pit must be the use of Rockley furnace, late in its life, for casting large cylindrical objects in vertical moulds. The pit, with its access, closely resembles seventeenth and eighteenth-century examples excavated at guncasting furnaces in the Weald of Kent and Sussex.

The Charging Ramp

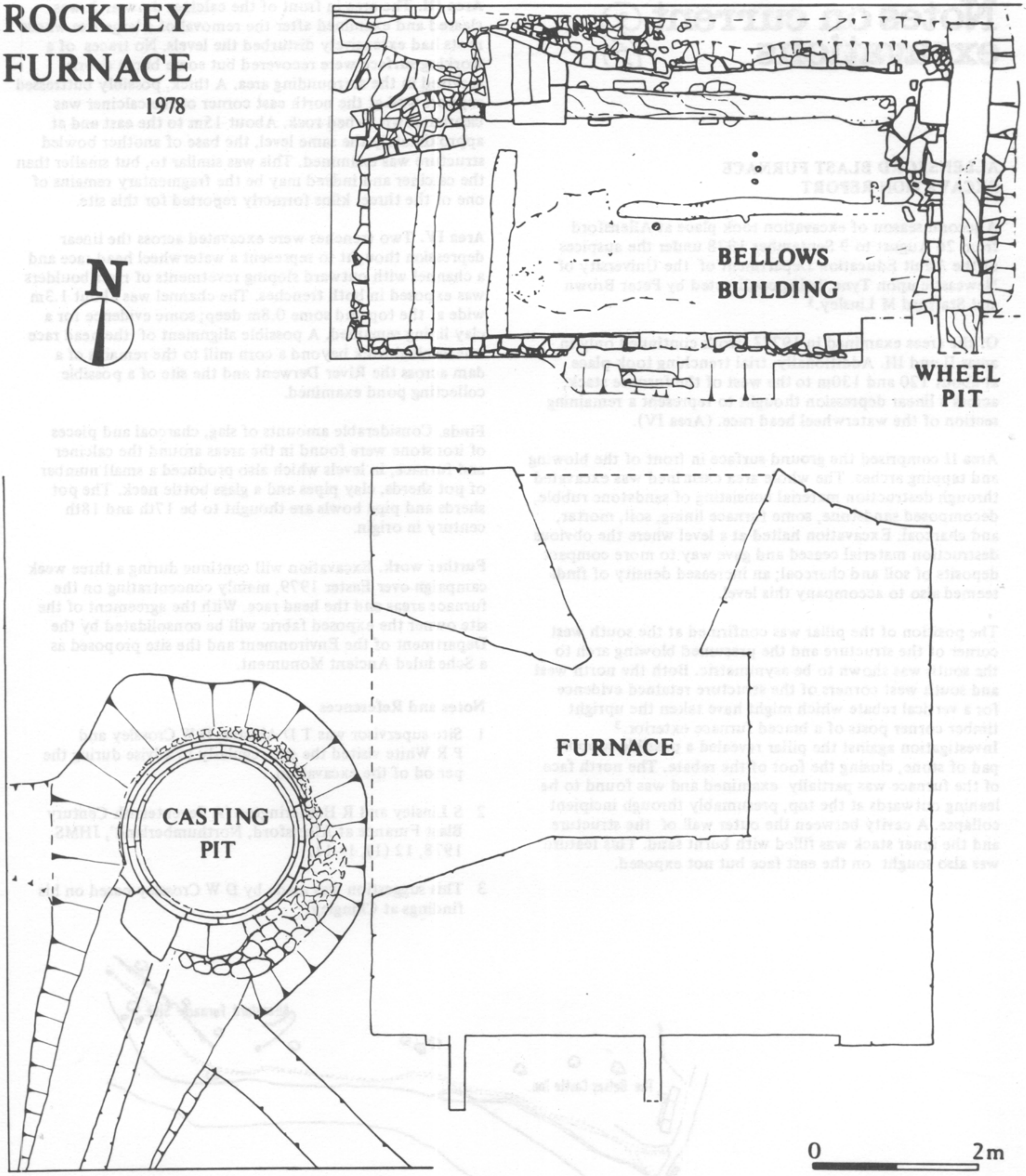
This feature is clearly visible to the south of the furnace. It has been established that a substantial masonry wall revets the sides of the ramp.

Future Work

Although the hearth of the furnace does not survive, it would be of interest to establish whether it was built over a pattern of drains, as seen elsewhere. In the 1978 excavations the probable exit of such a drain was found in the south side of the bellows house.

The major remaining questions can only be answered by work on the east side of the furnace. An opening in the eastern wall has long been the object of speculation, and its purpose may become clearer if adjacent levels are stripped. Further, the channel seen entering the wheel pit suggests that substantial features lie in this area. It is planned that more work will be carried out at Easter 1979.

ROCKLEY FURNACE
1978



Plan of the 1978 excavations

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Notes on current excavations 2

ALLENSFORD BLAST FURNACE EXCAVATION REPORT

A second season of excavation took place at Allensford from 26 August to 9 September 1978 under the auspices of the Adult Education Department of the University of Newcastle upon Tyne, being co-directed by Peter Brown and Stafford M Linsley.[1]

Of the areas examined in 1977[2], work continued only in areas II and III. Additionally, trial trenching took place at about 120 and 130m to the west of the furnace stack, across a linear depression thought to represent a remaining section of the waterwheel head race. (Area IV).

Area II comprised the ground surface in front of the blowing and tapping arches. The whole area examined was excavated through destruction material consisting of sandstone rubble, decomposed sandstone, some furnace lining, soil, mortar, and charcoal. Excavation halted at a level where the obvious destruction material ceased and gave way to more compact deposits of soil and charcoal; an increased density of finds seemed also to accompany this level.

The position of the pillar was confirmed at the south west corner of the structure and the presumed blowing arch to the south was shown to be asymmetric. Both the north west and south west corners of the structure retained evidence for a vertical rebate which might have taken the upright timber corner posts of a braced furnace exterior.[3] Investigation against the pillar revealed a possible support pad of stone, closing the foot of the rebate. The north face of the furnace was partially examined and was found to be leaning outwards at the top, presumably through incipient collapse. A cavity between the outer wall of the structure and the inner stack was filled with burnt sand. This feature was also sought on the east face but not exposed.

Area III. The area in front of the calciner draw arch was cleared and examined after the removal of a large tree whose roots had extensively disturbed the levels. No traces of a working surface were recovered but some burnt debris survived in the surrounding area. A thick, possibly buttressed support wall at the north east corner of the calciner was cleared down to bed rock. About 15m to the east and at approximately the same level, the base of another bowled structure was examined. This was similar to, but smaller than the calciner and indeed may be the fragmentary remains of one of the three kilns formerly reported for this site.

Area IV. Two trenches were excavated across the linear depression thought to represent a waterwheel head race and a channel with outward sloping revetments of river boulders was exposed in both trenches. The channel was about 1.3m wide at the top and some 0.8m deep; some evidence for a clay lining remained. A possible alignment of the head race was levelled back beyond a corn mill to the remains of a dam across the River Derwent and the site of a possible collecting pond examined.

Finds. Considerable amounts of slag, charcoal and pieces of ironstone were found in the areas around the calciner and furnace, in levels which also produced a small number of pot sherds, clay pipes and a glass bottle neck. The pot sherds and pipe bowls are thought to be 17th and 18th century in origin.

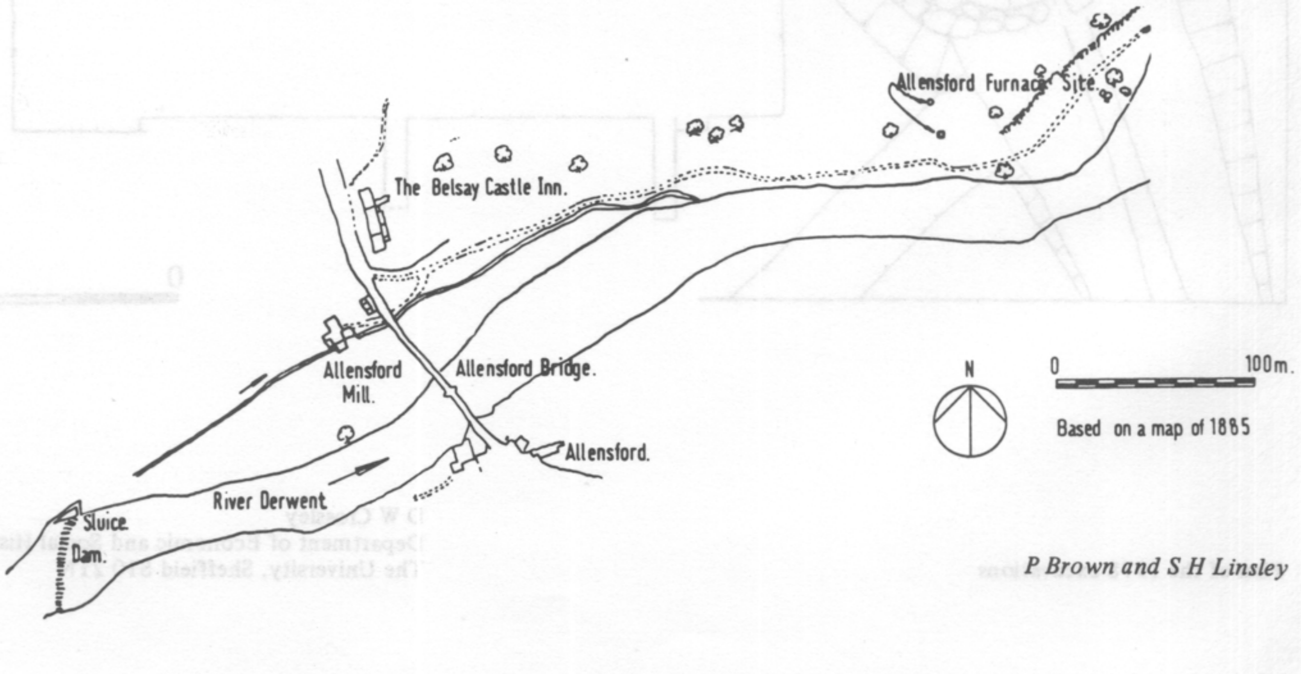
Further work. Excavation will continue during a three week campaign over Easter 1979, mainly concentrating on the furnace areas and the head race. With the agreement of the site owner the exposed fabric will be consolidated by the Department of the Environment and the site proposed as a Scheduled Ancient Monument.

Notes and References

1 Site supervisor was T D Akister; D W Crossley and P R White visited the site regularly to advise during the period of the excavation.

2 S Linsley and R Hetherington 'A Seventeenth Century Blast Furance at Allensford, Northumberland', JHMS, 1978, **12** (1), 1–11.

3 This suggestion was made by D W Crossley based on his findings at Chingley.



P Brown and S H Linsley

Book Reviews

CORROSION AND METAL ARTIFACTS. A dialogue between Conservators and Archaeologists and Corrosion Scientists. Ed B F Brown, H C Burnett, W T Chase, Martha Goodway, J Kruger and M Pourbaix. NBS Special Publication 479. Published by Superintendent of Documents, U S Government Printing Office, Washington, DC 20402 USA. Price $ 3.75 ($ 4.70 abroad).

This is the proceedings of a meeting held at the National Bureau of Standards in March 1976. It is profusely illustrated with more than 230 figures, which includes diagrams half-tones, and colour plates. It is a most interesting production and will be welcomed by practical conservationists and all those interested in the corrosion aspects of archaeo-metallurgy. It is extremely informal and although much of it is transcribed discussion it doesn't duplicate itself as do so many proceedings of conferences.

There is a good balance between the theoretical and the practical. M Pourbaix is allowed to introduce the subject with a paper showing the meaning and value of his diagrams, and we have contributions from such eminent corrosion and oxidation scientists as C E Birchenall dealing with reduction techniques. Practical aspects cover the corrosion and restoration of statues, illustrated, for example, by a set of 4 gilded bronzes set up in Washington in 1951, and also the hydrogen reduction of iron in the Swedish shipwreck, the Wasa.

Tucked away amongst all this are gems of detail such as a case of stress corrosion cracking in an almost completely oxidised, 4000 year old, tin bronze axe from Hasanlu. The author, Nielsen, attributes the stress component to the wedging action of the corrosion products. This same author draws attention to the difference in corrosion rates of high tin pewters (bad) and the higher leaded pewters (good).

One could go on giving examples; it is best, therefore, to say to all those interested in this subject, go ahead and buy a copy as soon as possible.

R F Tylecote

ARCHAEO–METALLURGY (Monograph number one) CHALCOLITHIC COPPER SMELTING, Excavations and Experiments, Beno Rothenberg, R F Tylecote, P J Boydell (Institute for Archaeo-metallurgical Studies, 104 Grafton Road, London, NW5 1978). Price £4.00.

This monograph is an excellent example of the current approach to archaeological investigation, which involves much more than the quest for 'pots and palaces'. Not only are the sites themselves excavated, they are studies within their environment: geographical, ecological, economic, etc.

Timna is an area of ancient copper workings on the west side of the Arabah to the south of the Dead Sea. The present study takes one site (39) from this region and deals, in the first section, with the archaeological excavations carried out, the stratigraphy and dating, and the metallurgy of the site. Two appendices report on the Flint Implements and the Phase Composition of the Slags respectively. The second section of the monograph deals with experiments on copper smelting based on early furnaces found at Timna, and contains a wealth of technical detail providing clear, if not yet completely definitive, information regarding the method and procedure of ancient copper smelting.

The actual production of the monograph is excellent. The text is well set out and the illustrations, line drawings, photographs, graphs, etc, are numerous and clear. This is a commendable first production of a proposed series of monographs from the Institute for Archaeo-metallurgical Studies which will be welcomed by and of value to the specialist and the serious archaeologist.

Institute of Archaeology, London. *J R Duckworth*

Archaeology at Bersham, Nr Wrexham, Clwyd. The County Planning Officer has published an illustrated booklet describing an archaeological excavation carried out on the 'East Works' site of the Bersham Ironworks (map ref SJ 309 492). The east work's site was developed from 1763 onwards by the internationally famous eighteenth century ironmaster and industrialist John Wilkinson in partnership with his brother William Wilkinson, and the concern was known then as the 'New Bersham Company'. The site contained rolling, slitting and boring mills, powered by water wheels driven by power supplied by the nearby River Clywedog.

The booklet contains (1) a brief account of the history of the site using drawings, photographs and maps to illustrate this and (2) a report on the excavation carried out in 1976 by an archaeologist supervising a Job Creation Team under the auspices of the Manpower Services Commission.

The report explains how maps and historical evidence confirm the presence of first an Iron Works and then a paper mill, and how excavation has revealed part of the layout of these buildings on the site.

Copies of the booklet can be obtained form the County Planning Department, Shire Hall, Mold, Clwyd price 75p.

Abstracts

GENERAL

J C Chaston: Gold and the beginnings of physical metallurgy; the pioneer work of Roberts-Austen. *Gold Bull.* **1977, 10** *(1), 24-26.*

Scientific investigation of gold alloys for the British Mint at the beginning of this century is outlined.

MH

C A Smith: Early electroplating: commencement of industrial applications (about 1836-1852). *Finishing Ind. 1977,* **1** *(3), 24-28.*

The historical development of electroplating is considered in relation to the rival claims of Jacobi, Jordan, Wright and Spencer for preeminance in the discovery of electro-typing and electroforming. The first patent which used electricity in plating is that of Elkington and Barrett in 1838. Progress in the electroplating of zinc in Europe is traced and the cyanide bath for the deposition of gold and silver is given. 13 refs.

MG

Anthony Smith: A history of tinplate. *Tin International 1977,* **50** *(3), 85-87.*

A review of manufacturing processes of tinplate, commonly thought to have begun in Bavaria in the 14th cent, up to 1835 is given. 11 refs.

C A Smith: Early corrosion investigations. *Corrosion, Prevention and Control. 1977,* **24** *(1), 6-13.*

A review of nineteenth-century studies of corrosion by Mallet, Davy, Stevenson, Adie and others is given which includes a summary of the work of Phillips on what is thought to be the first corrosion-testing equipment, and of Parker on the corrosion of iron and steels. 33 refs.

J H Westbrook: Intermetallic compounds: their past and promise. *Met Trans A, 1977,* **8A** *(9), 1327-1360.*

Discusses the use of Cu-Sn, Sn-Hg for mirrors and Cu_3As for decoration in early times, leading up to the appearance of purple plague ($AuAl_2$) in recent times.

The bulk of this most interesting and valuable paper by one of our longest serving members naturally deals with the last 100 years but it should be a reminder of what to look for in early artifacts.

RFT

J H Carlson: Analysis of British and American pewter by X-ray Fluorescence spectroscopy. *Wintertur Portfolio, 1977,* **12**, *65-85.*

Over 1,300 pieces of British and American pewter have been analyzed using energy dispersive x-ray fluorescence spectroscopy. A statistical analysis of the analytical data obtained for the four most important elements, tin, lead, copper and antimony, establishes general compositional characteristics for each form in both British and American pewter. Where statistically possible (ie. where sufficient numbers of a particular style, form, or maker were available) more detailed conclusions are drawn. Objects of anomalous composition are also discussed.

JHC (AA)

R F Tylecote: Durable materials for sea water: the archaeological evidence. *Int. J. Naut. Arch. 1977, 6, 269-83.*

Results of an enquiry commissioned by British Nuclear Fuels Ltd to establish what materials would be suitable for disposing of nuclear waste on the seabed. The requirement was for a material which could be expected to last for 1000 years at least. Consideration of various alloys from the earliest Bronze Age arsenical coppers onwards, and of corroded and uncorroded wreck material, led to the conclusion that a homogeneous lead-free high-tin bronze, such as was used in Dover MBA bronze hoard (some details appended), would be most suitable.

(BAA)

BRITISH ISLES

J H Carlson: X-Ray fluorescence of pewter; English and Scottish measures. *Archaeometry, 1977,* **19**, *147-55.*

Non-destructive chemical analyses have been made of 80 English and Scottish pewter measures. XRF analysis permits the simultaneous and rapid qualitative and quantitative determination of 13 elements present in pewter. Changes in composition with time, and variations in composition between English and Scottish measures, and between both with other pewter vessels, are discussed. A few anomalous (?late) compositions are noted. *Author (adapted)*

(BAA)

Martin Dean: Lead tokens from the River Thames at Windsor and Wallingford. *Numis. Chron. 1977,* **137**, *137-47.*

One hundred and twentyfour lead tokens recovered from the Thames by divers were cast in bivalve moulds and not struck. Eight design groups are evident, and the intended diameters appear to fall into three significant groups. The composition of the metal is apparently haphazard and bears no relationship to either design or size. Dating evidence and possible uses of the tokens are reviewed. *Author/Numis Lit*

(BAA)

B G Awty: Force forge in the 17th century. *Trans. Cumb. and West. Antiq. Soc. 1977, 77, 97-112.*

Accounts from 1658 show the forge being worked by Thomas Rawlinson. Typical of Furness forges of the time, it worked the ore in a fully mechanized version of the direct process. The three wheels, finery, chafery and hammer, used water-power only. The accounts throw light on all aspects; reasons for the trading loss of 1658-63 are discussed. The site is probably not where marked on the OS map but at 339909.

(BAA)

D G Hey: The ironworks at Chapeltown. *Trans. Hunter Arch. Soc. 1977,* **10**, *254-9.*

The 17th century ironworks at Chapel Furnace, S Yorks, now obliterated, is placed in its historical context from its construction by 1628, through its well-documented use by the Copleys from 1652 and the Spencer partnerships by the end of the century, to its development into the Chapeltown Ironworks after the 1760's. The likely form of the structure is suggested, by reference to the surviving Rockley Furnace of 1652. Surviving traces of mine-pits, and coppice-wood placenames, are noted in the Chapeltown district. The material for the later history of Chapeltown Ironworks is briefly reviewed.

DWC (CBA)

J K Almond: Production of iron and steel at Tudhoe works Co Durham. *Metall. Mater. Technol. 1977, 9 (3), 127-8.*

A short history describing the introduction of the Bessemer process, using four 2½ ton converters, to the works under what is thought to be the first licence granted by Bessemer. By about 1883 this process was replaced by open-hearth steelmaking. MG

K C Barraclough: A steel bar from Woolwich dockyard; a comment. *Post-Med Arch 1977,* **11**, *101.*

A plea for an agreed scheme of analysis before one concludes the origins of ferrous metal. Suggests chemical analysis of Si, Mn, S, P, (and perhaps Ni, Cr and Mo); check on uniformity of carbon across the section; and presence and distribution of slag and inclusions. RFT

Anne Hyelman: Lakeland iron. Leighton furnace; an excercise in site reading. *Ind. Arch. 1978, summer, 5 (2), 3pp.*

An interesting short account of the charcoal iron furnace, which is said to have been of an experimental nature, operated from 1713 until c.1806. Reference is made to the supplementing of an inadequate water supply by manpower, operating the bellows on the treadmill principle. The tiny site plan, unfortunately, is hardly legible, even under a glass. 3 refs. are given. HWP

H W Paar: Parkend's covered way. *Forest Venturer, No. 27, pp4–7.*

A plan of Parkend in 1877-8 is reproduced. A detailed account of the bridge which carried materials over the railway line, to the tops of the blast furnaces. Author

B G Scott: Metallurgical and chemical studies on a group of iron artifacts from the excavations at Greencastle, Co Down. *UJA, 1976, 39, 42-52.*

28 Medieval (13-16 cent) knife blades and a short sword. The knives show the usual techniques of combining iron and steel including welded-on steel edges and wrapped-round steel. The other artifacts were wrought iron with variable carbon content, ie. normal bloomery iron. Some knives had been hardened to give values between 351 and 468 HV. The sword, although inscribed, was pure ferrite with a hardness of 96HV. Some of the knives revealed maker's marks under radiography.

The source of the ore was variable and the local Antrim laterites were not represented. RFT

T R Slater: The old blast furnace at Maryport: its water supply system. *Industrial Archaeology, August 1973,* **10**, *318-324.*

Basing his research on maps and plans in the Senhouse Papers at the Carlisle Record Office, the author corrects previous work on this furnace by members of the Historical Metallurgy Group (now Society), particularly in regard to its leat from the River Ellen. The furnace was coke-fired from its beginning in 1754, and was a large one for its date. It had to share its water power with a corn-mill at Netherhall, which had priority in supply, and it is suggested that inadequacy of the water-power was a reason for its closure in 1783. DGT

T A Morrison: A brief history of the Merioneth Manganese industry. *Industrial Archaeology, February 1974,* **11**, *29-32.*

Summarises the story of mining for manganese ore in Merioneth, which took place mainly between 1886 and 1914, with an output of 68,079 tons. The ore did not require dressing and was sent by rail to Mostyn on Deeside. After about 1900 the Merioneth output was dwarfed by that from the mines on the Lleyn Peninsula. DGT

P J Foster, R Harper and S Watkins: An Iron Age Romano-British settlement at Hardwick Park, Wellingborough, Northamptonshire. *Northamptonshire Archaeology, 1977, No. 12.*

Iron Age enclosures dated to the 1st and 2nd century AD. Pottery and lime kilns. Some metallurgical evidence in the form of dross containing drops of leaded bronze found in ditch; also iron ore and iron smelting slag as well as iron working slag from smithing. ECJT

M and D Palmer: Moira Furnace. *Industrial Archaeology Rev, Autumn 1976,* **1**, *63-9.*

Gives the historical and geographical background of this blast furnace in Leicestershire, which survives in comparatively good condition. The furnace was built between 1803 and 1806 as part of a scheme of the Earl of Moira to exploit his mineral resources and the facilities of the Ashby canal. The furnace was charged from a canal bridge and served a foundry; it had steam-driven blast. It could not have been very successful, for the local coal was not good for coking and the local ironstone was of poor quality. It had probably ceased to work by 1851. Parts of the buildings were then converted to cottages.

NOTE: The historical background is widened in a note by C P Griffin, 'The historical background to the establishment of the Moira Furnace: a re-interpretation', *Industrial Archaeology Rev, Autumn 1977,* **2**, *85-8.* DGT

Anon: Workington celebrates 100 years of railmaking. *British Steelmaker, December 1977 (6), 13-16.*

Has a brief summary of the history of the plants and owners from c.1872. Steel rails were first rolled in August 1877, just over five years after the works opened. The Workington works is notable as being the last UK producer of Bessemer steel, closing in 1974. NM

C McCombe: Cast-Iron Grave Slabs reveal Seventeenth Century Founders' Skills. *Foundry Trade Journal, 1977* **143** *(3125) 1125-1129. Correspondence: Foundry Trade Journal, 1978,* **144** *(3131), 336.*

A little-known group of cast iron grave slabs in Burrington churchyard North Herefordshire, is described and illustrated. The earliest dates from 1619 and the most recent from 1765. Moulding and casting methods are discussed. The hypothesis that the castings were produced locally was given support by the subsequent discovery of an illustration of an eighteenth-century furnace a few miles distant from the churchyard. Despite the exposed position the lack of corrosion is remarkable.

In a subsequent letter to the Editor, M S Darby points out that Bringewood is probably the furnace referred to, listed by Schubert as having worked before 1601 until 1814 or 1815. The iron ore probably came from a site adjoining Waterloo Farm, Orleton Common, near Ludlow, the grid reference of the farm being approximately SO471692. APG

C McCombe: Preserving Britain's Foundry Vintage. *Foundry Trade Journal, December 22nd 1977,* **143** *(3127), 1324-1332.*

Proposals for a major museum, dealing with the history, development and achievements of the foundryman in Britain, to be housed in the Great Warehouse at Coalbrookdale are discussed at length. One or more working foundries are planned as part of a complex of buildings on the site. Illustrations show some of the patterns, castings and equipment which are already available for display. APG

Lawrence Ince: The Neath Abbey Ironworks: *Industrial Archaeology, 1977,* **12** *(1), 21-37*

The article summarizes the commercial history of the works for the period 1792, when the partners who owned an iron foundry at Perran Wharf, near Falmouth, decided to expand their interests to Wales, until final closure in 1875. An outline of the buildings and equipment of the works and of some of the more outstanding products – tram engines, high pressure engines, ships, railway locomotives and gas making plants – is followed by an illustrated description of buildings which remain on the site. Very brief mention is made of associated iron works at Venallt and Abernant.

Anon: Wooden Patterns Display. *Foundry Trade Journal 1978, 144 (3130), 229.*

Patterns, working drawings and other interesting items from Alfred Dodman & Co Ltd (founded 1850) were preserved when the works were pulled down in 1977 and patterns have been displayed in King's Lynn Museum. APG

R K Eborall: Marine Treasure Trove. *Metallurgist and Materials Technologist 1978,* **10**, *96.*

30 bronze cannons were recently recovered from the sea bed off Port Elizabeth, South Africa, from the 1647 search of the Portuguese galleon Sacramento. The best specimens have been kept as museum pieces, but the remainder have been melted down as scrap. Typical analysis shows 5% tin, 0.33% lead, 0.12% antimony, with very low percentages of other elements. The cannons are reputed to have been cast in Macao. APG

J Dearden: The Railways as DIY Steelmakers. *Metallurgist and Materials Technologist. 1978,* **10**, *191-193.*

One of the first Bessemer plants was installed at Crewe works in 1864 to make steel for rails, and several railway companies later installed their own facilities for steelmaking. This article is mainly concerned with the author's experience in the small steelmaking department at Horwich in the late 1920's but illustrations show the steel foundry and part of the test room ca. 1909. APG

D W Hadley: The Role of Iron in Reconstructing the Oxford Canal 1829-35. *J Rly and Canal Hist Soc., 1978,* **24**, *9-15.*

Oxford Canal Co letter and account books are used to survey the demand for iron for railroads (track and wagons) bridges and aqueducts, cast iron guards, iron boats and 'smith work', and the sources of supply during the period of reconstruction. The largest single cost was for rails. APG

R F Tylecote: Lead smelting and refining during the Industrial Revolution 1720-1850. *Ind Arch, 1977,* **12**, *(2), 102-110.*

The construction and operation of the ore hearth and slag hearth which generally made use of wood, peat or coke as fuel, are reviewed. Where suitable coal was available, the reverberatory furnace was used to extract lead. After the end of the 18th century, the practice of roasting the ore in reverberatory furnaces before charging to the ore hearth was introduced. Recovery of silver was by cupellation, the litharge produced by this operation being subsequently reduced back to lead. In 1833 the Pattinson process, for concentrating the silver in the lead before cupellation, was patented, and this process was soon introduced at the Blaydon Lead works. Since 1850 the Parkes process has replaced the Pattinson process, the mechanization of the ore hearth has produced the Newnam Hearth, the slag hearth has become the blast furnace, and the Dwight-Lloyd sintering machine has replaced roasting in the reverberatory furnace.

The characteristics of the remains which are still visible of equipment used in these earlier processes are briefly outlined. APG

B A Fyfield – Shayler and C P Norton: Finch Brothers' Foundry. *Ind Arch 1977,* **12** *(2), 134-140.*

These water powered works at Sticklepath, near Okehampton, were in commercial operation from 1814 to 1960 producing scythes, billhooks, axes, hoes, shovels and specialised tools for the mines and china-clay industry of Devon and Cornwall – the works never seems to have been a foundry in the technical sense of the word. In 1966 a charitable trust was formed to restore the buildings and equipment and it is hoped that in 1978 a blacksmith will be employed so that members of the public will be able to see the production of iron articles for sale. APG

H S Campbell, D J Mills: Marine Treasure Trove – A Metallurgical Examination. *Metallurgist and Materials Technologist, 1977,* **9**, *551-557.*

The results of a detailed examination of metallic artefacts recovered from the Gilstone Ledges, west of the Scilly Isles, are reported. Most of the artefacts came from ships of Sir Cloudesley Shovell's squadron wrecked on 21st October, 1707, and interesting comparisons were made with other relics, especially those salvaged with the Swedish warship Wasa, which sank in Stockholm Harbour in 1628. Wasa lay in water highly polluted with sewage effluent, poor in oxygen and rich in ammonia and hydrogen sulphide and when the ship was lifted it contained more than 700 tons of sludge. Storms are frequent at the Gilstone Ledges, with consequent frequent interchange of water between the surface and seabed. The force of the winter storms is sufficient to disperse the lighter wreckage and to shift around even the heaviest. The sea bed is largely composed of granite rocks and detritus, so that the environment may be regarded as typical of fully-aerated clean, ocean water.

Two bronze cannons, cast in France in 1635 and ca.1650 which have been recovered from the wreck of the Association on the Gilstone Ledges, were of very similar composition to the bronze cannon from the Wasa, ie. 4 – 4½% tin, ½ – 1% lead, and 1 – 1½% zinc. A small breech-loading gun, probably cast in England about 1700, was similar in composition to a Swedish gun of 1535 recovered in 1920, containing about 7% tin 2 to 2½% lead and ½% zinc. The rear part of a cast brass demountable gun from the Gilstone Ledges contained 22% zinc, 1% lead and 1% tin, together with 0.07% arsenic and 0.1% antimony.

The small breech-loading gun exhibited a cored denditic structure typical of cast bronze. The two larger guns showed an annealed structure, with heavy strain markings, and no evidence of coring. Although this was surprising a similar observation had been made on the gun from Wasa. In the latter case, the presence of an oxide scale in the bore of the gun suggested that annealing had been carried out after cleaning the bore, and that the gun had never been fired. Annealing the cast gun seems likely to reduce the wear resistant properties of the material and so be deleterious. No explanation can be offered for the practice. It is just possible that the two larger guns from the Association were annealed by the heat generated when the guns were fired, or perhaps by the heat generated during boring. The heavy strain lines were probably the results of deformation arising when the guns were rolling among the rocks on the sea bed.

The thin protective green corrosion product on one of the larger guns was identified. That on the smaller gun was similar, but was only moderately protective, despite the higher tin content and lower zinc content. This was attributed to the electrochemical effect of the comparative differences in the core structure, which had not been removed by annealing in the latter case. The brass gun had been partly cleared before examination, but the corrosion product remaining was principally cuprous oxide – evidence of the beneficial effect of the arsenic and antimony in preventing dezincification.

Two bronze sheaves, approximately 180mm od, 45mm thick and 35mm diameter were found to be made from 10% tin bronze with 10% lead – a very suitable material for the purpose. The character of the corrosion was very different in the two pieces. One appears to have been largely protected from corrosion by being in such close contact with ferrous metal that galvanic protection was provided. This sample was largely covered with a concrete like deposit of round flints and other stones from the sea bed bound together and to the metal by calcium carbonate. The cathodic process on the surface of the sheave would be reduction of dissolved oxygen in the sea water with the production of hydroxyl ions and consequent deposition of calcium carbonate. Those parts of the metal not covered with a concrete deposit or the remains of marine growth carried a nearly black, coherent, largely protective corrosion product layer of sulphide, indicating that for part of the time the component had been covered with silty mud in which there was some activity of sulphate reducing bacteria.

The second sheave carried a green corrosion product, which, over much of the surface, was overlaid with a deposit of iron oxide. Corrosion was much more extensive. Evidently it has been close to a ferrous article for quite some time, but not in such close contact that galvanic protection had been provided for the bronze.

A pair of dividers proved to be made from 20% zinc content brass, with sufficient arsenic and antimony to make the metal resistant to dezincification. However, some features of the corrosion attack were unusual, and reasons for this are discussed. The steel points had, as expected, corroded away completely.

The results of analysis of corrosion products on a lead weight and lead bullets from the Gilstone Ledges are discussed. In both cases the lead was better than 99% purity. Assuming that the artefacts derived from the 1707 disaster, the corrosion rate of lead at this site is approximately half that of lead bullets in Stockholm harbour. A lead spout made from two pieces of pipe soldered together was found to contain 0.005% silver, which indicates that it was produced before the general adoption of desilverisation in 1840. The very uniform wall thickness of the pipes, and the absence of a longitudinal soldered joint, seem to indicate that it was made by extrusion, a process which was not applied to the commercial production of lead pipe until 1820, but it may have been manufactured at an earlier date by casting a hollow cylindrical billet and driving this through holes in an iron plate.

A pewter platter was identified from the pewterer's mark as having been made not earlier than 1819. It had been cleaned before it was received for examination, but there appeared to have been very little corrosion. This was attributed to its composition – 11% lead, less than 1% antimony. By contrast a spoon made in an alloy containing 1% lead, 5% antimony and 1% copper was very heavily corroded, almost certainly because of its different composition.

APG

Anon: The Ironbridge. *Metal Construction and Brit Weld J 1976,* **8** *(6), 252-253.*

A short account of the design and construction of the first iron bridge opened at Coalbrookdale in 1779.

MG

H B Madsen: Specialist in Brooches. *Skalk 1976 (4), 12-15. (in Danish).*

The article briefly describes a bronze casting workshop from the Viking period at Ribe. Mold fragments of the tortoise-shaped Berdale type brooches are considered. The finds show that the brooches were cast into two-piece clay moulds. Small clay bellow-guards show that bellows were used.

HBM(AA)

J C Wright: 120 years of quality casting development. *British Foundryman 1976, 69 (7), 161-179.*

Historical development of quality steel castings since the initial British production of cast cog wheels and railway crossings in 1855 are reviewed. Illustrated and discussed are the introduction of manganese steels and other contributions from the Hadfields Hecla Foundry. Various safety factors are tabulated, and a worked example of the fracture-toughness approach to design for quality-assurance is given.

MG

Janet Lang and J Graham-Campbell: The scientific examination of a silver bossed brooch from Cuerdale, Lancs England. *Norw Arch Rev 1976, 9 (2), 127-8. (in English)*

An archaeological study of a silver brooch from England is presented. The composition and method of manufacture were studied.

(AA)

Peter A Clayton: Gold in the late Roman Empire; a gold goldsmith's workshop in Roman Britain. *Gold Bull 1977,* **10** *(2), 54-56.*

This paper discusses briefly the evidence for gold-working in Roman Britain and mentions mining, minting of coins, crucibles and an inscription from Yorkshire which refers to a goldsmith's workshop.

WAO

EUROPE

P T Craddock: The composition of copper alloys used by the Greek, Etruscan and Roman civilisations. 1. The Greeks before the Archaic Period. *J Arch Sci 1976, 3(2), 93-113.*

This paper is the first of four parts dealing with the composition of copper alloys used in the classical world. In this paper there is a discussion of previous analytical work and the use to which the analytical data may be put.

For published compositional analyses to be of use it is essential that details of the sampling, analytical procedure and standard deviation of the results be reported. The reasons for this are discussed in detail with examples from literature where failure to do this has made the interpretation of the reported analytical results difficult if not impossible.

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

P T Craddock: The composition of the copper alloys used by the Greek, Etruscan and Roman civillisations. 2. The Archaic, Classical and Hellenistic Greeks. *J Arch Sci 1977,* **4** *(2), 103-123.*

This paper is the second dealing with the composition of copper alloys used by the Greeks. About 500 analyses of Archaic, Classical and Hellenistic objects are published here pp 117-123 together with comments upon the alloys used. The data are arranged chronologically within broad limits and further subdivided typologically. The techniques of sampling and analysis are discussed in depth in the first part of this project (Craddock, 1976).

The development of casting technology is one of the principal features of bronzeworking during this period. Our knowledge of Greek casting technology comes both from archaeological excavation and from a careful examination of the castings themselves. Evidence from these sources has been brought together here for the first time together with the comments of medieval, renaissance, and modern technical authors to attempt a coherent picture of the way the superb Greek bronzes were produced and adorned.

It was during this period that the Greeks started using mercury gilding on copper and bronze; and the techniques and range of gilded metal are discussed. AA

Miriam S Balmuth and R F Tylecote: Ancient copper and bronze in Sardinia; excavation and analysis. *J Field Arch 1976,* **3** *(2), 195-201.*

Analysis of 4 Cu oxide ingots from the Cagliari Museum by emission spectroscopy for Sb, As, Bi, Co, Fe, Pb, P, Si, Mn, Ni, Ag, Sn, Zn, Te and Al showed that they probably came from the same ore deposit and that they were probably not imports from Cyprus. Additional analyses of ores and fluxes from Sardinia will be needed before these ingots can be assigned a local origin. (AATA)

R Thomsen: Bog ore and farmer iron. *Jernkontorets Ann. 1976,* **160** *(5), 38-42 (in Danish.)*

The history of iron production in the last 2000 years is presented. In the Scharmbeck furnace from 200 AD, the iron producers were able to reach a yield of 14 kg Fe/100 kg bog Fe ore consisting of 38% Fe, 17% MnO_2 and 23% SiO_2. The last plan for iron production in Denmark was made in 1918, but never realized due to economic depression following World War I. (AATA)

P T Craddock: The composition of copper alloys used by Greek, Etruscan and Roman civilisation; the origins and early use of brass. *J Arch Sci 1978,* **5**. *1–16*

Production of brass probably started in the 1st millenium BC in Asia Minor. It was not made in Greece and there are few signs of it in Etruria. The Romans used the cementation process in the 1st century BC for coins and other purposes. It formed 30% of Roman copper alloys by the 2nd-3rd century AD but by then was not being used for coinage. Discusses the origins of the term 'brass' and the chemistry of the cementation process. RFT

Anon: Bronze statuary. *Fonderia Ital. 1976,* **25** *(11), 271-275. (in Italian).*

Bas-reliefs and statues cast in bronze before 1751 are discussed, including examples of the durability and advantages of bronze. The molding and casting procedures are described. MG

H J Kostler: The production of shear steel in the former Innerberg forges. *Radex Rundschau; 1976, Dec. 814-827. (in German).*

A detailed account derived largely from contemporary descriptions of the practices used in the early steel industry in the area of Austria between Eisenerz and Steyr is given. This industry was based on bloomeries and finery hearths and lasted from about 1625 to 1881. Selection, reheating and piling are described fully. MG

M Bukowski: Industrial buildings in Upper Silesia, *Industrial Archaeology, Nov 1973,* **10**, *357-366 and 449-455.*

A brief account of the development of iron blast furnaces and lime kilns in this region of Poland, illustrated with seven plates of blast furnaces dating from the eighteenth and early nineteenth centuries, and plates of a zinc works dated 1825 and several lime-kilns. DGT

H–G Bachmann: A find of litharge on the Nordeifel. *Bonner Jahrb. 1977, 617-622. (in German).*

A note on the composition of litharge from the Roman settlement excavated by von Petrikovits. The phases present are $PbCO_3$ (cerussite), alpha PbO (litharge) and copper oxide. Shows how the cupellation process was carried out. RFT

F N Tavadze, V I Sarrak and G V Ivanishvili: The mechanical properties and nature of the fracture of archaeological iron. *Soobshch. Akad. Nauk Gruz SSR. 1976,* **80** *(2), 409-412.*

Tensile and impact toughness tests are reported for cylindrical specimens of an archaeological iron containing 0.1-0.4% C in the non-heat treated condition. Tensile tests established a large number of sites of the occurrence of plastic deformation localized mainly at sites of low carbon content. Ductility was considerably below that of contemporary material of the same ultimate tensile strength. Most of the fracture surface is occupied by areas of brittle shear with a characteristic ray-like pattern. The lower mechanical properties are explained by the large quantity of slag inclusions at the fracture surface. Impact tests reveal brittle fracture tendencies even more than do static tests. MG

R Cesareo:and F W v Hase: Analysis of Etruscan gold alloys of the 7th cent. BC by a portable radio-isotope excited X-ray fluorescence unit *Applied Nuclear Methods in the field of Works of Art. 1976, 259-296. (in Italian).*

About 200 analyses were carried out on Etruscan gold alloys using a portable XRF unit. This unit uses a proportional xenon gas counter and a Pm^{147}/Al source as 'measuring head' and a single-channel analyzer. The concentration of Au, Ag and Cu is obtained from three counts corresponding to window positions of the analyzer, centered on the three element X-lines, according to prefixed calibrations. Furthermore, objects were analyzed which had been made by the goldsmith Castellani, during the last century, in imitation of similar Etruscan objects. The composition is obviously different from the composition of the true Etruscan artifacts. MCU

C Conophagos: Smelting furnaces and the technique of smelting argentiferous lead ores of Laurium in ancient Greece. *Ann. Geol. Pays. Hell. 1974,* **26,** *338-66 (in Greek).*

An archaeological study is presented of appearance and analyses of highly siliceous scoria. It is estimated that production totaled 1.3 million tons Pb and 2.6 million kg, Ag, mostly in the 4th and 5th centuries BC (AATA)

R F Tylecote: Properties of copper ingots of Late Bronze Age type. *Festschr. fur Richard Pittioni, Wien, 1976, Vol 2, 157-72.*

Describes tests on plano-convex ingots from Cornwall, Surrey and Essex and (for comparison) some RB ingots. It is shown that the LBA smelters were able to achieve purities up to 99.8% (ignoring sulphur and oxygen). Two Mediterranean ox-hide ingots were also examined. (BAA)

H H Coghlan: Some aspects of the study of prehistoric non-ferrous metallurgy. *Fest. f. R. Pittioni, Wien, 1976, Vol 2, 28-39.*

Summarizes European research since the late 1950s and discusses the kinds of problems remaining. (BAA)

C Eibner: Alloys or natural deposits? *Fest. f. R. Pittioni, Wien, 1976, Vol 2, 43-57. (in German).*

Discusses the premises underlying the interpretation of results of prehistoric metallurgical analyses. (BAA)

Otto Schaaber: An investigation of Pliny's statements on iron based on metallurgical finds. *Jahresheften des osterreich. arch. Inst. 1976-77,* **51,** *85-105 (in German)*

Uses spark-maching to extract a long, thin (2 mm), metallographic specimen. Shows examples of the technique applied to objects from Magdelensberg such as nails, chisels and blooms (18.5 kg). Not only has this site produced wrought iron but it has also produced steel (0.3-1.8%C) and cast iron (>1.8% C).

A Sherratt: Resources, technology and trade; an essay in early European metallurgy. in. *Problems in Economic and Social Arch.. Ed. G. de G Sieveking, I H Longworth and K E Wilson. Duckworth, London 1976, 557–581.*

Poses and answers questions as to why metal tools were used since the advantages over stone were not very great. Discusses the problem of the links between metal producers and consumers using modern arch. parallels. Follows the movement of materials in Neolithic Europe with special reference to the Carpathian basin which first supplied rock suitable for stone tools such as flints and obsidian, and later native metals and copper ores.

Deals with the appearance of different alloys on the European scene and shows how far the objects made from them acted as status symbols or were traded in the early bronze age; finally, with the smiths' hoards of the LBA. RFT

B Jovanovic: Rudna Glava and the beginning of metallurgy in the Central Balkans. *Boll. Cent. Comuno Studi Preistorici, 1976,* **13-14,** *77-90 (in English).*

A note on the famous Yugoslav Cu/Fe mine worked from early Eneolithic times. The deposit is a cupriferous magnetite. Objects such as stone hammers, amphorae-jugs, clay altars etc, have been found in levels indicating Vinca and earlier dates. RFT

G Sperl: The Hallstatt iron fibulas from Leoben-Hinterberg. *Der Leobener Strauss. 1977 (5), 9-15. (in German).*

Consists of a fully oxidised piece of iron showing slag stringers in hematite and magnetite. It was possible to make a reconstruction. RFT

A P Jouravlev and E L Vroublevskaya. The initial stages of metal working in Karelia. *So. Ark. 1978 (1), 154-165. (in Russian).*

The eneolithic tribes belonged to the ceramic cultures of lozenge-and-dimple decoration which existed on the two sides of L Onega in the 3rd millenium BC. This was the earliest metal working centre in the North. Derived from a predative economy in an area with numerous deposits of native copper in schist and quartz. Uses qualitative spectroscopy to compare the native metal and the objects.

Gives microstructures showing the typical bent twins of worked native copper, and hardnesses in the range 56-90 HV. RFT

L S Khomoutova: The treatment of iron in the villages of the Diakovo culture. *Sov. Ark. 1978 (2), 62-77. (in Russian).*

A detailed metallographic examination of 197 iron tools and weapons from the Middle Volga region and dated from the 2nd to the 8th century AD. Two centres can be identified; one at Chchbinskoi shows simple and primitive techniques while that at Troitzkoi shows a more developed range of techniques. The results discuss the hardness, carbon content and microstructure; only carbon was determined. The specimens show the usual range of carburized iron and welded iron and steel structures expected for this period. RFT

R Maddin, J D Muhly and T S Wheeler: How the Iron Age began. *Sci. American, 1977,* **237** *(4), 122-131.*

Claims that the E Mediterranean had mastered carburizing and quench hardening of iron by the 7th century BC. The claim is based on the existence of pearlite, the intentional welding of steel to iron to make an adze blade, and a pick from Mt. Adir in Israel which had a hardness of 38 R_c, and other objects. Shows an SEM of a fully oxidised pearlite revealed by gold-covered replication. RFT

I R Selimchanov: A question about the Arsenical-copper age. *Germania, 1977,* **55** *(1-2), 1-6. (in German).*

Notes the increasing appearance of this alloy as a result of comprehensive analytical programs and considers Coghlan's question as to whether one should speak of an arsenical-copper age. He introduces some analyses from the N Caucasus site of Stavropol giving values in the range 1.5-19.3%As. He concludes; that in the Near East and the N Caucasus Cu-As alloys are more common than bronzes; that one might speak of a Cu-As period; that the oldest find of Cu-As is from Cayönü Tepesi and dates to the 7th millennium BC (C-14). RFT

ASIA

K R Maxwell-Hyslop: Sources of Sumerian gold. *Iraq, 1977,* **39,** *83-86.*

Preliminary results of an investigation of the Ur goldwork from the Brotherton Library of the University of Leeds. Consists of granular beads formed into a ring, a fragment of strip, and a sheet metal bead. One granule contained 100% Au; others 9-20% Ag and 0.5 to 5% Cu. At least one bead contained platinum-rich inclusions. Discusses possible sources of the gold but does not comment on whether the 5% Cu is natural or not. RFT

V I Sarianidi: The earliest axes from Afghanistan. *Sov. Ark. 1978 (2), 186-194. (in Russian).*

Bronze Age shaft-hole axes and clay moulds with cores from prehistoric Bactria. Earliest types similar to Lauristan bronzes. Typological. Discusses anthropomorphic characteristics. RFT

T S Bartseva: The chemical composition of a bronze cauldron found in the village of Gaiidara; *Sov. Ark. 1978 (2), 256-7. (in Russian).*

4 pieces (or areas) including a knife. Tin bronzes with and without lead and 0.6-2.5% As. RFT

Shanghai Chiaotung University: An investigation of the bronze 'Tou Kuang Ching' (magic mirrors) of the West Han Dynasty. *Chin Shu Hsueh Pao 1976,* **12** *(1), 13-22. (in Chinese).*

The optical effects were re-examined with models reproduced on the basis of historic knowledge with the same alloy (Sn 22-4, Pb 2-5%, and the rest Cu) and designs of varying thickness, ways of cooling, and also with grinding to an even thickness. Results of physical experiments revealed that local stresses and relaxations as well as a convex bending of the mirror surface caused by the design (including 2 ring-shaped reinforcements) are responsible for the behaviour. (AATA)

J Birmingham: Spectrographic analyses of some Middle Bronze Age metal objects from Palestine. *Levant 1977,* **11,** *115-120.*

Of this group of seven bronzes – two axes and five toggle pins – there are five high-tin lead-rich bronzes (inc. the two axes), one arsenical copper and one impure copper. The results are only semi-quantitative on a scale of 8 steps. MJH

Prentiss S de Jesus: Metallurgical practices in early Anatolia. *Bulletin of the Mineral Research and Exploration Institute of Turkey. 1977, No 87, 49-63.*

A survey of sites south of the Black Sea. Scant evidence of mining and smelting; some slag and tuyeres (?) found; no dates. ECJT

J D Muhly, T S Wheeler and R Maddin: An iron axe of the 5th-4th century BC from Al Mina. *Levant, 1977,* **11,** *156-161.*

The technique of manufacture has been deduced: onto a roughly shaped piece of iron bloom was hammer-welded a second portion of iron bloom hammered first into a sheet and carburized. This layering technique produced a tool with strong working surface economically; the carburization process is discussed and other ancient examples are mentioned. MJH

K M Linduff: The incidence of lead in Shang and early Chou ritual vessels. *Expedition, 1977,* **19** *(3) 7-16.*

The metal of early Chinese bronze ceremonial vessels consistently contains lead as an alloying constituent. The thesis is examined that this was associated with plumbism in Chinese people at that time. Various elemental analyses are noted from the literature. JW

R Maddin, T S Wheeler and J D Muhly: Tin in the ancient Near East; old questions and new finds. *Expedition, 1977* **19** *(2), 35-47.*

The origin of tin remains an unsolved question of the Near Eastern Bronze Age. The geology of tin deposits in relation to possible ancient sources of tinstone (cassiterite) is reviewed, and various metallurgical characteristics of tin explained. Relevant textual evidence and the rare archaeological finds of metallic tin are covered. Two tin ingots inscribed with signs of a Cypro-Minoan type have been found in Israel. Preliminary elemental analyses and metallographic studies are presented here and their possible significance assessed.. JW

O P Agrawal: Conservation of cultural objects: Asian materials and techniques – Bidri. *Museum, 1975,* **27** *(4), 193.*

Bidri ware is a special type of metal work with a deep black, smoothly polished background and shining silver inlay. The base used in *bidri* is an alloy of zinc, copper and lead. Zinc and copper are mixed in a ratio of 16:1. This alloy takes a black colour when rubbed with a particular clay. It was found in the village of Bidar in South India. Inlay was done with silver wire. Deterioration and preservation methods are discussed. (OPA(AA)

L Bacon and K Janposri: The Thai bronze project. *Studies in Conservation, 1977,* **22** *(1), 32-39.*

The Thai Bronze Project was a joint venture between the Fine Arts Department of Thailand, the John D Rockefeller 3rd (JDR 3rd) Fund, New York, and the Freer Gallery of Art, Washington, DC. The project lasted for one year. The Anglo-American team of visiting conservators treated bronze objects, mainly using benzotriazole (BTA), and instructed Thai personnel in modern techniques. A survey of the bronze collections of the museums of Thailand was carried out and recorded. An attempt to judge the need for environmental control in museums was made by leaving temperature and humidity gauges on open display and in show cases. An exhibition was held on 'Bronze Disease and its Treatment'. AA

F Weinberg, D M Jacobson and J Pelleg: An investigation of ancient metal objects from the North Sinai Coast. *Metallography, 1977,* **10** *(2), 171-8.*

Materials analysis was performed on archaeological Cu-bronze objects from the North Sinai coast. Conventional metallography, nondispersive analysis of composition, and electron microprobe analysis were used. (AATA)

M Osawa and N Yamamoto: Consideration on the new examples of 'Tettei', rectangular iron plates. The relics from the Hanasoge tomb, No. 2, Ogori, Fukuoka prefecture.

Kokogaku Zasshi *(J Arch Soc Jap) 1977,* **62** *(4), 20-50 (In Japanese).*

The newly found 16 pieces of 'Tettei', rectangular iron plates with spreading ends in Hanasoge tomb, No 2, Ogori, Fukuoka Prefecture were studied not only archaeologically, but also chemically. A sample contained C 0.69-0.89%, Si 0.047, Mn 0.002, P 0.014, S 0.018-0.046, Cu 0.002, V 0.003, etc. It is a pure steel, and low contents of Cu and Mn are remarkable. KY

K Yamasaki and M Murozumi: Lead isotopes in ancient bronze mirrors and coins excavated in Japan. *Arch and Nat Sci. 1976 (9), 53-58 (in Japanese).*

Lead isotope ratios in five Han mirrors, four Wei mirrors (triangular-rimmed mirror with god and animal designs), one Han coin, four Northern Sung coins, and one Japanese coin (14th century) were determined by mass spectrometry. The isotope ratios are different for the Han and Wei mirrors suggesting different origins of lead ores used for making mirrors. The isotope ratios of Northern Sung coins belong to another different group. The Japanese coin shows the same lead isotope ratios with the galena ores occurring in Japan. KY(AA)

T S Wheeler and R Maddin: The techniques of the early thai metalsmith. *Expedition, 1976,* **18** *(4), 38-47.*

The article is based on metallographic an electron microscopic examination of nineteen metal objects from Ban Chiang and nine from Non Nok Tha. Dates were from around 3600 BC to the 500-0 BC period. Most objects were cast, often with cold working; ten metallographs exemplify these and other points. Unusually interesting examples are a ring of copper-zinc alloy, a necklace of high tin content (both 500-0 BC) and a spearhead with bronze socket and iron blade (1600-1300 BC). More complete results will be published in the future. JW

N Seki: Maitreya in Hanka-pose of the Yachuji temple as seen from the point of sculptural techniques. *Ars Buddhica. 1976 (110), 75-99. (in Japanese).*

The height of this maitreya in the meditation pose is about 30 cm and was cast from top to the platform in one operation. The details were studied by gamma-ray radiogram. Inscriptions on the platform were made after gilding. The casting techniques were discussed in detail. KY

AFRICA

A R Williams and K R Maxwell-Hyslop: Ancient steel from Egypt. *J Arch Sci. 1976,* **3** *(4), 283-305.*

Iron objects excavated at the turn of the century at Thebes in Egypt, but possibly of Assyrian or Urartian origin, were examined chemically and metallurgically. Three objects consist of wrought iron containing appreciable amounts of slag. Two had been case-hardened along their cutting edges, increasing the hardness about threefold. Two specimens were of fairly homogeneous steel (0.1-0.2% C) which had been hardened by quenching. CWB

T Benfey: Editor's page; waiting to see King Tut. *Chemistry 1977,* **50** *(5), 2.*

Mention is made of the fact that x-ray examination of the inlaid gold funeral mask revealed that it was made from a single piece of gold without seams or joints. HMP

J B Donne: West African goldwork. *Connoisseur, 1977,* **194** *(780), 100-106.*

Briefly discusses techniques of gold-working used in several West African cultures. Information is drawn mainly from historical documents. CIL

E W Herbert: Aspects of the use of copper in pre-colonial West Africa. *J African Hist. 1973,* **14** *(2), 179-194.*

Copper and its alloys were for centuries staples of the import trade of West Africa across the Sahara long before most local deposits were worked. Uses were mainly for medium of exchange, ornament, insignia of rank and objects of cult and magic. In the latter it was superior to gold. RFT

AMERICA

Anon: Tests of Drake's brass plate indicate fake. *Chem and Engg. News 1977,* **55** *(32), 6-7.*

A news item describes recent analyses of 'Drake's plate' found on the California coast and supposedly left by Sir Francis Drake in the 16th century. Workers at the Lawrence Berkeley Laboratory conclude that it was most probably made in the late 19th or early 20th centuries. Workers at Oxford University maintain that an equivocal conclusion cannot be drawn. JW

E R Caley: Composition of Peruvian native gold. *Ohio J of Sci 1977,* **77** *(2), 141-143*

Samples of placer gold from various sites were found by gravimetric analysis to contain over 90% gold with silver as the other major component. Iron was present as a minor component in all samples in the form of entrapped hematite or magnetite. ERC

P M Dinsdale: Let freedom ring; the manufacture of the bicentennial bell. *Found. Trade J. 1976,* **141** *(3096), 690-692.*

The bell was fabricated from an alloy of about 77% copper and 23% tin, the metal being poured at 1100°C into a mold made from loam built up around a brick foundation. Details are given of the machining of the bell to obtain the desired musical pitch. MG

V F Hanson, J H Carlson, K M Papouchado and N A Neilsen: The Liberty Bell; composition of the famous failure. *Ameri. Sci. 1976,* **64** *(6), 614-619.*

English 18th century bellmaking methods are described, along with the history of the Liberty Bell, cast in 1751. Elemental analysis of the bell was carried out in Independence Hall, Philadelphia, by energy dispersive x-ray fluorescence spectroscopy using a portable instrument The average of 13 separate analyses at different locations showed the main constituents to be Cu 67.08, Zn 1.40, Pb 3.25 and Sn 26.89%. Minor elements were Fe, As, Au Ag and Sb. The significance of the composition is discussed. The crack in the bell may have been caused by stress-corrosion cracking, although there is no certain evidence for this; it was not caused by strains produced during cooling. EWF & JHC

D B Heller and D L Fennimore: The restoration of a William Will teapot. *5th Annual Meeting of AIC, Boston. Preprints. 1977, 62-71.*

The authors describe the conservation and curatorial considerations involved in restoring the three feet of a pewter teapot by William Will. The molding, casting and joining of replacement feet is presented; Dow Corning's Silastic A-RTV rubber was used for the initial mold; a britannia alloy (91Sn2 Cu 0.5 Pb 6.5Sb) was employed for the castings to differentiate the new feet from the original (91Sn 0.75Cu 5.25Pb 3Sb); the solder chosen was 70Sn 30Pb. On the basis of measurements and visual comparisons, the authors conclude that many components in such teapots were mass produced in the eighteenth century. PAL

J H Carlson: X-ray fluorescence analysis of metal artifacts from the Caleb Pusey House. *Trans Delaware Acad. Sci. 1976, 317-331.*

Energy dispersive x-ray fluorescence analysis has been applied to more than fifty pewter, silver, and brass artifacts recovered during the excavation of the 18th century Caleb Pusey house in Upland, Delaware County, Pennsylvania. Analysis has, in the case of a 17th century pewter plate and certain other pewter objects, confirmed attributions as to provenance and age. In other cases, such as that of a Britannia spoon bearing a crowned X mark, analysis has shed new light on the object's origin. JHC(AA)

H L Peterson: American Indian Tomahawks. *Contributions, Museum of the American Indian, Heye Foundation, 1965,*

The article includes information on the terminology, history, and geographical distribution of tomahawks, their uses and ceremonial functions, and the various types. Methods of production from European rifle barrels and other sources of

metal are described. There is an appendix 'The Blacksmith Shop' by Mildred G Chandler, in which the set-up of the shop, tools, equipment, and various techniques of manufacture are described. There are photographs of over 300 pieces.
BAp.

Marc Simmons: Blacksmithing at Zuni Pueblo. *The Masterkey, 1973,* **47** *(4), 155-157.*

The article is a discussion of an 1851 illustration of a Zuni Blacksmith shop and the equipment shown in it. The shop is in Spanish style, probably manned by Mexicans. The double bellows originated in eastern Asia and spread to the Mediterranean. Tools of the Anglo-American blacksmithing tradition are absent. The engraving is reproduced in the article.
BAp

J R White: X-ray fluorescent analysis of an early Ohio blast furnace slag. *Ohio J Sci. 1977,* **77** *(4), 186-188.*

Results are given of analyses of nine samples of slag recovered from excavations at the site of the Eaton-Hopewell Furnace, the oldest blast furnace (1802-1812) west of the Alleghenies. These results indicate that the firing temperatures were considerably lower than those employed today,and that both charcoal and soft coal were used as the fuel.
ERC

A R Rosenfield: The crack in the Liberty Bell. *Int. J Fract. 1976,* **12** *(6) 791-797.*

The Liberty Bell is given as an example of a failure which had its origin in the necessity of using a brittle alloy (bell metal is a high-tin bronze) for a large casting put into service without further heat treatment. The problem was compounded by improper operation and maintenance nearly 200 years ago.
MG

Associacao Brasileira de Metais: Charcoal-based iron and steel production in Brasil. *Assoc. Brasil. Met. San Paulo, 1977, 236 pages. (in Portuguese).*

An illustrated account of the use of charcoal as fuel in present day iron smelting and steelmaking.
MG

R H Schallenberg & D A Ault : Raw Materials Supply and Technological Change in the American Charcoal Iron Industry (1866-1910 approx). *Technology and Culture, July 1977,* **18** *(3), 436-466.*

The economic and technological problems of wood as a factor of production have been treated too simplistically by past historians and in fact the economics of ore supply had at least as much to do with the decline of the charcoal iron industry as did problems of wood supply. This is largely due to the choice of a static model – the iron plantation – from which to derive technical 'constants' (ie. data). Wherever charcoal ironmasters could take advantage of supplies of cheap rich ore to produce large amounts of iron which were reasonably competitive with coal irons, they did so, eg. Michigan, Wisconsin, Alabama, Tennesee. Larger furnaces permitted the use of charcoal-saving innovations which, because of expense, were not feasible for small scale smelters. The use of new ores and the adoption of innovation were both necessary to compete with coke smelting. In the old shape of furnace (illustrated) the descending mass of the burden was fairly nonfluid and sluggish, due to too low temperature and pressures of blast. A wide flare of the stack and a large diameter bosh were needed to prevent hanging. The newer furnaces were narrower in cross-section at the bosh and had multiple tuyeres, giving more uniform and fluid conditions throughout the cross-section and thus more homogeneous iron. The old lower-shaft furnaces required 240 to 150 bushels charcoal to make 1 ton of iron, the newer furnaces only 120 to 72.9 bushels. There is no evidence of increasing cost of wood (and hence charcoal) over the period and the evidence suggests there was no change. In some cases, wood or charcoal was moved considerable distance by rail eg the Isabella furnace, Pennsylvania had its fuel railed 300 miles – this was cheaper than local wood deliveries. Advances in charcoal making in the second half of the 19th century increased production from 35 – 38 bushels of charcoal per cord of wood to a maximum of 60-65 with byproduct recovery. There is sound evidence that lack of proximity to large deposits of high grade ore was a very important factor in the decline.
APG

AUSTRALASIA

G T Bloomfield: The Kawau Copper Mine, New Zealand. *Industrial Archaeology, Feb 1974,* **11**, *1-10.*

Discusses, and presents photographs of the remains of, the short-lived copper mining and smelting industry on Kawau Island in the Hauraki Gulf. Acitvity lasted from about 1843 to 1851. Shafts, engine house and smelting house remain, in derelict condition. Cornish influence in mining was strong; smelting was started in 1848 using experts from Swansea.
DGT

TECHNIQUES

H McKerrell: X-ray analysis of early copper alloys. *Appl. of Nucl. Methods in the field of works of art. 1976, 317-336.*

X-ray fluorescence analysis was used to determine the composition of a large number of artifacts and to classify the alloys into one of a number of sub-heads including copper, arsenical copper, tin, bronze, leaded bronze, brass and combinations of these. Isotope excitation (Pu-238 , Pm-147, Am-241) has been used to utilize the K, x-ray of tin, silver and antimony, rather than the usually excited L, x-ray more susceptible to surface roughness and composition variations. The use of surface analysis with corroded or uncleaned objects permits identification of special surface treatments such as arsenic plating or segregation.
MCU

P Meyers, L van Zelst and E V Sayre: Interpretation of neutron activation analysis data of ancient silver. *Report, 1976, BNL21513. 20p. (INIS Atomindex, 1977,* **8** *(2), Abs.282752).*

Results from work on Sasanian silver and objects from related periods and geographic provenances are used to demonstrate that analytical data in combination with other properties can be used with reasonable success in establishing groups of objects of common geographic provenances, in providing information on the production, use, and distribution of silver metal, and on ancient metal working techniques.
(AATA)

G J Varoufakis: Chemical polishing of bronzes. *Archaeom. 1977,* **19**, *219-21.*

A new non-destructive method is described for chemical polishing and etching of the surface of ancient bronzes before metallographic examination. The method has been applied to the analysis of 9th century BC Greek bronzes in both laboratory and site studies; in the field, replicas were taken and transferred to the laboratory. *Author (abridged)*
(BAA)

W A Oddy: The production of gold wire in antiquity; hand making methods before the introduction of the draw-plate. *Gold Bull. 1977,* **10** *(3), 79-87.*

This paper briefly reviews the literature on the history of wire making and discusses both the archaeological and historical evidence for thedate of theintroduction of the draw-plate. It is concluded that only a microscopic examination of surviving wire will solve this question, and the paper goes on to describe the characteristics of hand-made wire, as a basis for the future study of existing wire from antiquity.

WAO(AA)

B G Scott: Problem of the possible application of age-estimation by fission track counting to the study of bloomery slags. *Arch Rozhledy, 1976,* **28**, *333-334. (in English).*

The note suggests that the technique of estimating age by counting of fissiontracks in slag could possibly be used in the study of ancient iron produced by the bloomery process. Counts could be made on furnace-bottoms which could then provide C^{14} age-estimations from the entrapped charcoal which these usually contain. These results could then be used to calibrate those produced by counts from slag particles found during metallographic examination of bloomery iron.

BGS(AA)

R Wellum: Investigations into the measurement of noble metal concentrations in ancient silvers by radiochemical activation analysis. *Appl. Nulcl. Meth. in the field of works of art, 1976, p 43-46.*

After neutron activation of silver, the detection of the presence of the platinum metals, ruthenium and osmium was not possible. Only palladium and irridium have proved amenable to investigation.

MCU

E G Thomsen and H H Thomsen: An analysis of wire making in antiquity. *Proc. North Amer. Metalwork. Res. Conf. 1976,* **4**, *140-6.*

A discussion of ancient wire making of the gold rhyton type attributed to the 6th to 5th centuries BC in Persia was presented. It was concluded that only drawing could be accepted as the realistic process to produce wire of that fineness.

(AATA)

R Cesareo and M Marabelli: X-ray fluorescence analysis of ancient Italian doors made of copper alloys. *Appl of Nucl Meth. in the field of works of art 1976, 409-420. (in Italian)*

Description of the measurements, carried out on copper alloys, employing portable radioisotope x-ray fluorescence equipment. This unit permits non-destructive quantitative determination of copper, zinc, tin and lead in the alloy in a measuring time of about 10 seconds. The 3 doors of the Florence Baptistry and 8 doors of the S Marco Basilica in Venice have been analysed.

MCU

R M Organ and J A Mandarino: Romarchite and hydroromarchite; two new stannous minerals. *The Canadian Mineralogist. 1971,* **10**, *916.*

Black crystals and white crystals found on tin pannikins lost in Boundary Falls, Winnipeg River, Ontario, between 1801 and 1821 were identified as SnO (romarchite) and stannous oxide hydrate (hydroromarchite) respectively The mineral names relate to Royal Ontario Museum Archaeology.

RMO(AA)

P Reimers and F Bodenstedt: Non-destructive determination of the alloy components of ancient Greek coins. *Appl of Nucl Meth in the field of works of art, 1976, 68-75. (in German)*

Activation analysis by means of 14 MeV neutrons was applied. Silver and copper have been activated by means of the following reactions ^{107}Ag (n,2n) ^{106}Ag and ^{63}Cu (n, 2n) ^{62}Cu; only the relation of the activity $^{62}Cu/^{106}Ag$ has been studied and the coins' density has been measured using a high density liquid (1,9665 g/cm^3). From the measurement of the density and the ratio Cu/Ag it is possible to calculate the concentrations only if no other compounds and no cavities are present.

MCU

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