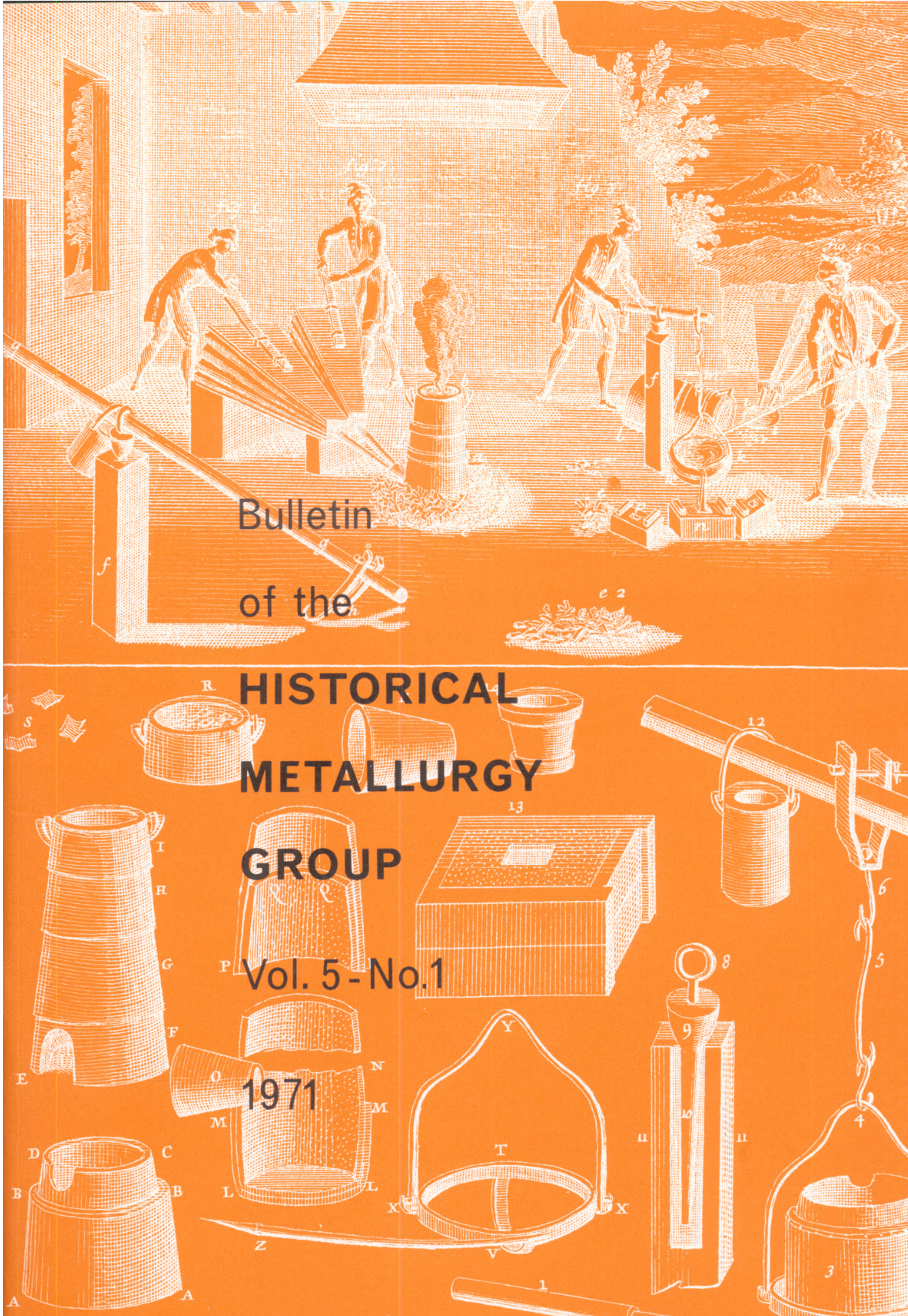

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Washing alluvial gold ores. Lazarus Erker, UCP translation p 99.

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Conference Papers

Work in Progress

Sixth Annual Conference: Swansea, 4–6 September 1970

The Group's conference this year was held in the University College of Swansea and the subject was the industrial history of the Swansea region and in particular the copper industry. About fifty members attended. The conference opened on the Friday evening with an introduction to the subject by Emeritus Professor Hugh O'Neill. Then we were told about the places that we would be seeing in the course of our tour next day by D. W. Hopkins, A. P. Greenough, and R. O. Roberts who were to be our guides. The details of the old hand mill process for making tinplate were demonstrated with the aid of a film which was introduced by H. Prescott, the Llanelli Borough Librarian.

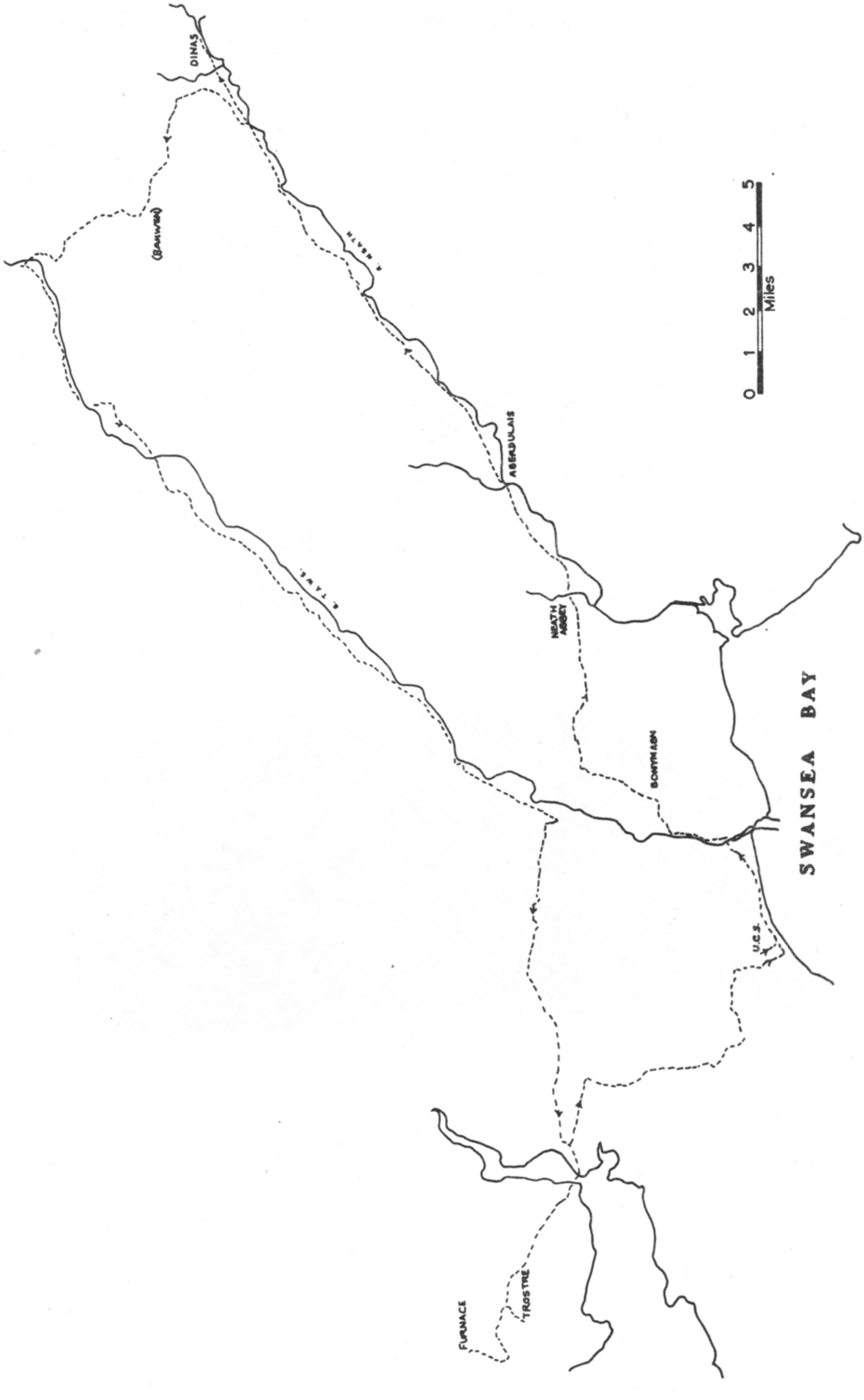
Next morning the party set off on a tour of the sites (see map). We passed the Royal Institution of South Wales in the centre of Swansea itself and then on to Bonymaen to view the Lower Swansea Valley sites of famous copper smelters. A stop was then made at Neath Abbey to see two blast furnaces dated to c. 1795. The state of these furnaces impressed the group: one at least would be well worth preserving and at little cost. We then visited the site of the 16th century copper smelter at Aberdulais, where there is supposed to have been one of the first reverberatories. The situation was impressive with a very adequate water supply and the area is now well wooded. It would certainly benefit from a detailed examination from an archaeologist, but its more recent metallurgical history would make the elucidation of the early processes used very difficult.

The party then took a picturesque walk along the upper reaches of the River Neath to see the Craig-y-Dinas silica mine which was responsible for many of the refractories of the 19th century copper plants. After this we had a well earned lunch. We then went across the ridge into the next valley, passing through the Clydach nickel refinery and the Velindre tinplate mill, finally arriving at the museum of the Trostre tinplate works, where we were entertained by D. C. Williams and given an excellent tea. The tour ended with a visit to the 1796 blast furnace at Furnace, Llanelli. A close view of this site had been made possible by the valiant efforts of A. P. Greenough and his colleagues in clearing the dense undergrowth the day before.

In the evening we assembled to hear D. W. Hopkins give his paper on the Welsh copper process. This is the process upon which the Swansea copper industry was based, and the lecturer clearly explained the difference between this and the earlier German process. Next morning we were treated to an exhibition of pictures and documents arranged by D. W. Hopkins and after, our Secretary, D. W. Crossley of the Economic History Department of the University of Sheffield, talked about his excavations at Panningridge and Chingley in the Weald. He had found two blast furnaces on the former site, and a finery and a chafery on the latter site which is still being excavated.

During the course of the conference there were many opportunities for discussions on various topics of interest to members. Where possible, the lectures were followed by lively discussions and contributions from members. It was altogether a very enjoyable week-end and the catering was excellent. We would like to thank the staff of Sibly Hall and the University College of Swansea, and Professor O'Neill, Mr. D. W. Hopkins, Mr. R. O. Roberts, Mr. A. P. Greenough, and their colleagues for making it so enjoyable and rewarding.

R. F. T.


DINAS
(BANWEN)
R. NEATH
ABERDULAIS
NEATH ABBEY
BONYMAEN
R. TAWE
SWANSEA BAY
U.C.S.
TROSTRE
FURNACE
0
1
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3
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Miles

Notes on sites visited during the Swansea Conference

NEATH ABBEY IRONWORKS

Iron was made at the Abbey in the 13th century, and there was a blast furnace in production nearby in 1715. In 1792, a Quaker family named Fox, Peter Price (trained at Coalbrookdale), a Mr Taylor, and one or two others—with one exception residents in Cornwall—founded the Neath Abbey Iron Company taking over the existing furnace and rolling mill. Some of them were partners in the Perran foundry, and their object appears to have been to supply iron cylinders and heavy castings for the Cornish pumping engines, hitherto usually obtained from Coalbrookdale.

However, the company built up a large engineering works at Neath Abbey, at one time employing 400 men in the construction of mill and pumping engines, and from 1829, railway locomotives. Large quantities of iron castings (e.g. tramplates) were also produced, but they refused to take part in the manufacture of cannon and other weapons for use in the Napoleonic war. For many years they enjoyed a great reputation for fair dealing and for the highest quality workmanship, but in later years the blast furnaces do not seem to have been used much. In 1840 Crane (Ynyscedwyn Ironworks) successfully brought an action against the Neath Abbey Iron Company for infringement of the patent for combining hot blast with anthracite or stone coal in the manufacture of iron. The works closed down in 1874, but were reopened in 1875. Final closure took place in 1885 or 1886.

The principal remains are the two blast furnaces built soon after 1792. The original drawings of the furnaces in the Glamorgan County Record Office show No. 1 furnace as 51½ ft high and No. 2 furnace 63½ ft, exceptionally high for the period. Both were in blast in 1798, 'each producing upwards of thirty tons of pig iron every week', blown by iron bellows worked by a Boulton and Watt engine with a steam cylinder 40 in. dia. (Visit by courtesy of Mr Matt Price, Neath)

ABERDULAIS

Situated at the junction of R. Neath and R. Dulais, Aberdulais has a plentiful water supply. The Mines Royal Copper Works (1584) was probably located here; later there were iron forges and furnaces and a tinplate mill. In 1864 it used Bessemer steel for tinplate. (Visit by courtesy of Dr Norman Thomas, Dulais House)

RABY'S FURNACE, LLANELLI

Alexander Raby sold Cobham Park in Surrey and moved to Wales, bringing the purchase money of £175,000 with him. His first venture was to construct an iron furnace at Penrhiwtyn, Neath, which was in operation in 1795, probably using coke as fuel. Shortly afterwards he moved to Llanelli, and took leases to establish collieries in 1797 and 1798. About the same time he took over the blast furnace built by Messrs Givers and Ingman in 1791, which he operated between 1802 and 1815. For a time, charcoal was the fuel used, but later coke made from the small coal was substituted. After the Peace of Amiens (1802), Raby bought large quantities of guns, which were treated by a method which he devised for separating an 'amalgam' of iron and copper, and at the end of the war with France, he similarly bought large quantities of cannon.

Raby was also responsible for the construction of the Carmarthenshire Railway, a public tramroad authorized by Act of Parliament in 1802 (the second such railway act in Britain) and opened from the Carmarthenshire Dock to Cynheidre in 1803, and to Cwm-y-Glo, Cross Hands, in 1805. However, the ironworks and railway were failures. Today the Llanelli furnace is the best preserved example of its kind in South Wales.

A sample of material (ore?) excavated in 1966 was analysed by the Steel Company of Wales Ltd (now part of BSC Strip Mills Division) as follows (dry): FeO 5. 4%, Fe_2O_3, 36. 68%, SiO_2 33. 71%, Al_2O_3, 4. 54%, CaO 1. 10%, MgO 0. 43%, S 0. 10%, P 0. 048%, Mn 0. 38%, CO_2 2. 42%, free C 6. 90%, combined H_2O 6. 80%, total Fe 27. 55%. The ore is reputed to have been brought from the Five Roads area, and later from Cross Hands.

DINAS SILICA MINE

This mine, situated near Craig-y-Dinas (Neath Valley), produced very pure silica. About 1800 this was used at Neath for repairing copper furnaces and the deposits were leased by W. W. Young in 1822. He worked at Swansea Pottery and in 1820 found that silica sand bonded with 1% lime could be fired to make silica bricks, and he established a brickworks at Pont Walby, 1 mile down the river. Until recently brickmaking continued at Landore on the site of the Siemens steel works.

TROSTRE MUSEUM

The year 1955 saw the closure of the last works producing tinplate by the hot pack process, thus ending an era which had been a cornerstone in Welsh industrial life. They had been superseded by the modern strip mills housed in the mammoth complexes at Ebbw Vale, Trostre, and Velindre.

When the Trostre plant was built at the turn of the fifties the management of the then Steel Company of Wales saw fit to reconstruct a derelict farmhouse that lay adjacent to the site. The building was recreated in roughly the style of its times for the joint purposes of acting as an official guest house and as an industrial museum. This attractive building now sits in its own grounds overlooking the works and houses a unique collection of objects particularly related to the tinplate trade and the localities involved. The indoor collection is varied, with such things as working models, costumes, tools, photographs, office records, and union sanctions, whilst in the grounds there stands some of the original hand mill machinery.

The museum and its collection have aroused the interests of many organizations, including the Welsh Arts Council, who intend using some of the exhibits in their current project entitled 'Work'.

CONFERENCE PAPER

The industrial metallurgical history of the Swansea region

HUGH O'NEILL

During its 1969 Conference, the HMG examined the winning of tin and copper ores in Cornwall and thereby provided a fitting introduction to one part of the metallurgical story of the Kidwelly-Swansea-Port Talbot region. Cornish ore was shipped over here after the Society of Mines Royal had turned its attention to Wales and sponsored copper smelting near Neath (Aberdulais ?) in 1584. According to a letter from one of the German workmen employed, both mineral coal and charcoal were used, but the increasing shortage of wood and the availability of a variety of cheap coals with refractories, limestone, rivers, and seaports eventually made Swansea (Abertawe) a great metallurgical centre during the Industrial Revolution.

COPPER

Subsequent copper works in 1698 at Melincrythan (Neath) and from 1700 at Neath Abbey showed that ore from Cornwall was following the South Wales coal, but this did not apply appreciably to the tinstone. Tin and lead were being smelted in Swansea from 1769 but the former was never a major product. Copper, however, became established on the Tawe after Lane smelted his father-in-law's Cornish ore in 1717, and other works were soon started. Anglesey ore was also imported in 1768, and the so-called 'Welsh Copper Process' developed around 1783.

About this time John Vivian of Truro began the family interest in copper mining and smelting, and in 1790 had concluded a works experiment at Penclawdd (Burry estuary) confirming the economic soundness of shipping ore to South Wales and taking coal to the tin works on the return journey. The reign of the Copper Kings was at hand.

His German-trained son John Henry landed at Swansea in 1806 from the Ilfracombe packet, and four years later bought the once lovely 'hafod' (summer residence) plot by the river. Here he started the famous Hafod Works, realising that ore could be shipped up the Tawe. Smelting and rolling prospered: by the middle of the century Swansea yielded three-quarters of the world output, and John Henry Vivian became the acknowledge head of the copper trade in Britain. At his house in Singleton [the nucleus of University College where the Group held its meeting] he entertained the future Queen Victoria and scientists such as Humphrey Davy and the great Faraday. In this 'European Conservation Year 1970' it may be mentioned that Faraday was called in to try and cure the serious atmospheric pollution resulting from the furnace fumes.

After 1827 ore imported from abroad swelled the output and by 1880 the region from Llanelli to Neath had 90% of Britain's copper-smelting capacity, including also the world's first electrolytic refinery at Pembrey (1869). Peak production from 13 works had been reached by this time, but at 15, 000 tons/year was only a quarter of world output, and decline set in. Smelting finally ceased in 1921, but refining and wrought copper and brass manufacture continued, with various mergers leaving today only the Landore Works of Yorkshire Imperial Metals Ltd and Nevill, Druce and Co. Ltd at Llanelli.

When foreign competition led to the decrease of copper production, a search was made for other manufactures. The Vivians imported copper ores rich in silver and gold and silver-rich lead ores from Spain, so that in 1880 the Hafod Works had an average monthly production of 30, 000 oz silver and 300 oz of gold, as well as 50, 000 oz of silver from the Spanish ores whose lead was rolled into sheet. Williams, Foster and Co. Ltd at the great Morfa Works also produced 5 tons of nickel and 1 ton of cobalt per month in 1874.

NICKEL

Sir Hussey Vivian, son of John Henry, became manager at the Hafod in 1846 and forms a link with our nickel industry. When the Canadian Pacific Railway was being driven through Ontario in 1883 it cut into a copper-nickel ore deposit near Sudbury. Sir Hussey had visited Canada in 1877 and the firm afterwards secured some mines of their own in Ontario. Following Riley's 1889 paper, steelmakers were showing an interest in nickel steels, and small amounts of concentrates were brought to Swansea and refined by a wet process at Hafod Works from 1889-1894. At about this time Ludwig Mond in Smethwick had devised his nickel carbonyl process and decided to go into business.

In 1899 he bought mineral properties near Sudbury and considered a site for a refinery. Clydach in the Swansea valley was selected because it was near the port for bringing in concentrates, and also near to anthracite and coke for making producer gas and water gas; moreover, he was attracted by the skill of the Swansea smelters. So the Mond Nickel Co. Ltd started at Clydach in 1901 and by 1940 was reputed the largest nickel refinery in the world. The process has been modified and the factory was reorganised in 1968, where it continues to produce increasing amounts of nickel pellets, with iron, nickel, cobalt, and copper powders and various nickel salts.

ZINC AND LEAD

Zinc and lead ores were mined in Britain in increasing quantities during the 18th and 19th centuries, reaching a peak production around 1845. Some were smelted by the English zinc process in Swansea which in 1830 yielded about 5000 tons, most of the world's output. Townsend's Upper Bank Zinc Works started around 1757; later, when copper production declined there was an increasing interest in spelter, especially after the invention of galvanized iron in 1837 and of yellow brass for sheathing ships. For instance, around 1841 Vivians converted a former copper works into their Morriston Spelter Works and later introduced more efficient continental furnaces and (in 1868) some German workers. Production had increased to about 15, 000 tons during 1870, but by this time it was only 12% of the European output.

From 1876 the Swansea Vale Works operated at Llansamlet on imported concentrates (e.g. from Broken Hill, Australia) and, although during the first World War about 75% of the total British output was produced in South Wales, our national weakness in zinc manufacture was revealed. Developments then took place at Avonmouth, leading in 1929 to the Imperial Smelting Corporation which took over this works. The retort process was in use, but in 1950 Avonmouth invented the zinc blast furnace and the first 'standard' model operated at Swansea from 1960. This successful plant produced 1165 tons of zinc in one week during 1968, with lead and sulphuric acid as well.

IRON, TINPLATE, AND STEEL

There was an influx of English ironmasters into Monmouthshire around 1700 and first charcoal iron and then rolled tinplate were produced. Later on, the introduction of the dry and the wet iron puddling processes and the coke and the anthracite iron blast furnaces enabled coal to replace charcoal, and the industry based on South Wales ores spread westward along the coalfield and down the valleys. Tinplate was made at Kidwelly in 1750, and river flats on the Tawe-for instance at Ynys-cedwyn (nr. Ystradgynlais), Ynysmeudwy (nr. Pontardawe) and Ynys-penllwch (nr. Clydach)—had their plants, those at Aberdulais and Upper Forest having developed on the sites of water grist mills. At nearby Cwmavon in 1849 the Copper Miners Company developed a large iron works (7 blast furnaces) and a copper works, with a fume flue cut into the mountain side leading to an ornamental chimney at the 1200ft summit. Here at one time water from a 600yd pipeline operated a 20ft diam. Pelton wheel which worked hand-type tinplate mills.

The first commercially successful Siemens acid steel plant in Britain commenced at Landore, Swansea, in 1869 and produced rails, bars, and plate, whilst extensions in 1871 included blast furnaces for smelting imported hematite. By 1880, 41 out of 64 tinplate works in South Wales were located west of Port Talbot in the river valleys, which provided water for steam and also for descaling and washing the individual plates during processing. Iron foundries for casting rolls and ingot moulds were built, and basic open-hearth furnaces increased in number. Swansea was the world centre of tinplate production by 1890, but then the McKinley Tariff greatly reduced our exports to the USA.

The period 1920-30 was a time of industrial depression which gave place to what has been described as the 'second Industrial Revolution' for Wales. A concentration of the small uneconomic tinplate works had begun about 1923, and the objective became large integrated steelworks with labour-saving wide hot-strip mills such as the one which started in USA about this time. Following the installation of the mechanized Ebbw Vale strip mill in 1938 and World War II, the Steel Company of Wales Ltd was formed in 1947 to modernize the industry. Its Abbey Works at Port Talbot was completed in 1950 and Trostre Works (Llanelli) came into operation in 1952, where 7 ton coils of hot-rolled strip from Abbey Works are cold-reduced and tin-coated by a continuous electrolytic process introduced from the USA. This was followed by the opening of a plant with continuous annealing, pickling, and tinning facilities at Velindre (Swansea) in 1956. The last of the old-type mills closed in 1961.

The Revolution continues, for this year at BSC Port Talbot the great new ore jetty has been opened and, instead of Siemens furnaces, two 300 ton basic oxygen converters aim at an annual output of more than 3 m tons of ingots for sheet, strip, and plate at competitive prices.

ALUMINIUM

The approach of World War II and rearmament had a new influence on our metallurgical development. Near Resolven (Neath) a small aluminium smelter to work on current generated from anthracite duff was planned in 1938, but the Swiss machines did not arrive before war broke out and so it was powered from the Grid. A similar reduction plant at Port Tennant, Swansea, also operated from the Grid during 1942-44, but both smelters were dismantled after the war and converted and extended to make rolled products and wire respectively from imported metal.

In 1939 the Ministry of Aircraft Production asked ICI to build and run at Waunarlwydd a factory for wrought aluminium alloys from ingots shipped into Swansea, and this has since changed ownership and been greatly extended. In the same year the Wern tinplate works at Briton Ferry was converted to making rolled aluminium products. During 1966 South Wales manufactured about half the UK output of sheet, strip, wire, and cable.

Swansea has not failed to attract the production of some less common metals, and in 1937 the Magnesium Metal Corporation Ltd built a plant at Port Tennant which yielded magnesium powder but was discontinued after the war. On the other hand, Imperial Metal Industries (Kynoch) Ltd produce wrought titanium alloys at their Waunarlwydd factory, for which there is likely to be a growing market.

THE PRESENT POSITION

This metallurgical story outlines many ups and downs: one peak made Swansea 'Copperopolis', another 'the centre of the zinc industry', and another 'the home of tinplate', whilst in nickel production scientific drive has preserved our European lead. Depressions, on the other hand, caused copper workers to emigrate and use their skills in the New World and New South Wales, followed by the export of tinmen and plant to North America and Italy. There remained in the Swansea Valley only the ruins of works and an estimated 7 m tons of slag, but these are now being cleared up, trees are being planted, and workers' condemned dwellings are being replaced. In this Second Industrial Revolution the region's prospects for nickel refining, zinc production, aluminium fabrication, and steel strip and tinplate manufacture by continuous processes are good, though these depend upon imported raw material with oil partly replacing coal. Atmospheric pollution is being controlled and the more efficient plants reduce costs, without which industry would once again decline. These plants are associated with a phase of unemployment, but I know that leaders such as those who have interested themselves in the Industrial Museum of South Wales are concerned to attract diversified user industries which will employ our available workpeople.

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CONFERENCE PAPER

The Welsh process of copper smelting

D. W. HOPKINS

INTRODUCTION

Accounts of 15th and 16th century copper metallurgy include references to roasting and matte smelting, refining by oxidation, and final reduction by charcoal. Oxide and carbonate ores were recognized as useful for reaction with copper and iron sulphides, and there was extensive retreatment of slags and fume. In some cases the copper and iron sulphides were separated from the gangue as a first step, but in others there was a preliminary roast. Fluxes capable of forming liquid slags were known under the description of 'stones which melt easily in the fire'. Some copper was produced by repeated 'roasting' of matte, but there are indications that most was made by smelting dead-roasted ore or matte in a shaft furnace with charcoal. Stirring with green wood was practised in order to remove oxygen and produce malleable copper at the end of the oxidation refining operation. Where necessary, silver was removed by alloying with lead and then liquating out the lead-silver alloy. The unit size of charge was a few hundred pounds and refining was carried out on about 250 lb of blister copper. Repeated treatment, depending on the appearance of samples, was necessary for production of satisfactory material. Whilst certain slags must have been rich in copper, there is evidence from Rio Tinto that much of the waste slag contained as little as 0.2%-0.6% Cu.

COPPER IN SOUTH WALES

The earliest reference to copper smelting in Swansea mentions a furnace near the castle in 1479. This was either extremely small or had gone out of use by the time the Mines Royal Society decided to establish a copper smelting works in South Wales in about 1580. This Mines Royal Society was the result of collaboration between German miners and smelters who had come to Britain in 1561 by invitation, to assist in the development of the indigenous copper industry. They had formed the Society of Mineral and Battery Works in 1565 and were smelting copper at Keswick and in Cornwall before coming to South Wales. Grant Francis[4] states that the first furnace was at Melincryddan on the eastern side of Neath, and there is certainly a local tradition that this was so, but later evidence appears to support more firmly the view that the furnaces were at Aberdulais, some two miles up the Neath Valley from the centre of the town. Contemporary correspondence indicates that the scale of operation was large, by the standards of the times, and that a reverberatory furnace was used to smelt about 24 cwt of ore a day. The move to South Wales resulted from a realization of the economies possible if the ore was taken to an area where coal was mined, since several tons of coal were required for the production of one ton of metal. Because of irregular deliveries of ore, this smelter was forced to close after a few years and by about 1660 there was virtually no smelting of copper in Britain

COPPER IN SWANSEA

The discovery of substantial deposits of copper ore in Cornwall and the abolition of the monopoly of the Society of Mines Royal resulted in a rapid expansion of the British copper industry from about 1680, and smelters were established at Melincryddan in 1695 and at Neath Abbey before 1700. The first copper smelter to be built in Swansea at this time was the Llangafelach works at Landore in 1717, and this was quickly followed by the Swansea Copper Works, on the site of the old Cambrian Pottery, in 1720. The total British production at this time was about 1000 tons a year and by 1750, when it was about 4000 tons, half of this was produced in the Swansea area. At the peak of the Swansea copper industry in about 1890, 90% of the British output came from this area. This concentration and continuing growth over a long period certainly originated in the availability of large quantities of cheap coal of superior burning characteristics. It was assisted by the availability of fireclay and limestone, and especially by the local development of high-quality 'Dinas' silica bricks from about 1790 onward, but the principal reason was the development of the Welsh process of smelting, whereby a high efficiency of metal recovery was combined with large capacity and less use of fuel than was previously the case. Viewed from the present day, it can be seen as a synthesis of the principles established at least two centuries earlier, with those of countercurrent operation and utilization of chemical information which are still being developed in contemporary smelting.

The earliest date at which the Welsh Process was in general use was probably about 1750, since the works set up in 1717 and 1720 smelted dead-roasted ore in shaft furnaces. The year 1856 is regarded as that in which copper smelting, in the fullest sense, was at a peak, because the ore suppliers were sending an increasing amount of copper as blister after this date. For example, between 1855 and 1885 the proportion of copper exported from Chile as blister bar rose from 40% to 95%. Import bounties and the special conditions of the 1914-18 war prolonged the life of what was by that time a hopelessly out-of-date industry and it ceased effectively in about 1921.

THE WELSH PROCESS

This process was normally carried out in six stages, all of which were intended to remove impurities by oxidation. In two of the stages solid material was exposed to air at elevated temperature and in the other four the charge was molten at the end of the treatment. The final product was tough pitch copper, containing such precious metals as were originally present and those base metals like nickel which could not be eliminated by oxidation.

The ores used in the heyday of the Welsh Process were those which are found very rarely in the 20th century: 'Some of the Australian ores reaching Britain in 1843-46 yielded 40% copper and those of Chile from 20-60%'. Even Cornish ores contained 8-10% Cu, and these were considered poor stuff when compared with Cuban ores containing 27% Cu. (The 19th century smelters would not welcome the ores containing 0.3-0.5% Cu which are now being treated at a profit).

Process control in the early stages was by making sample trials of each batch of ore and then calculating furnace charges and treatment times on the basis of the results. As chemical analysis developed, so the need for trials was eliminated. The basis of treatment was the production of blister copper at the end of the fifth stage of the process. This depended on the material from the fourth stage having a high copper content and being substantially free of iron. Attainment of this composition depended upon oxidation of iron and sulphur in the first four stages by a combination of oxygen from the air and from copper oxides in the slags recycled from later stages. The final waste slag only left the system after contact with matte rich in iron sulphide and so was free from chemically combined oxide copper. That which was present was in the form of very small globules of matte or metal which had not had time to settle out. The flowsheet shown in Fig. 1 is based on a drawing made in 1877.

The number of stages required for the production of refined copper depended on the copper and iron sulphide contents of the original ore.

The first stage for pyritic ores was calcination to remove sulphur to the extent that the residual amount was sufficient

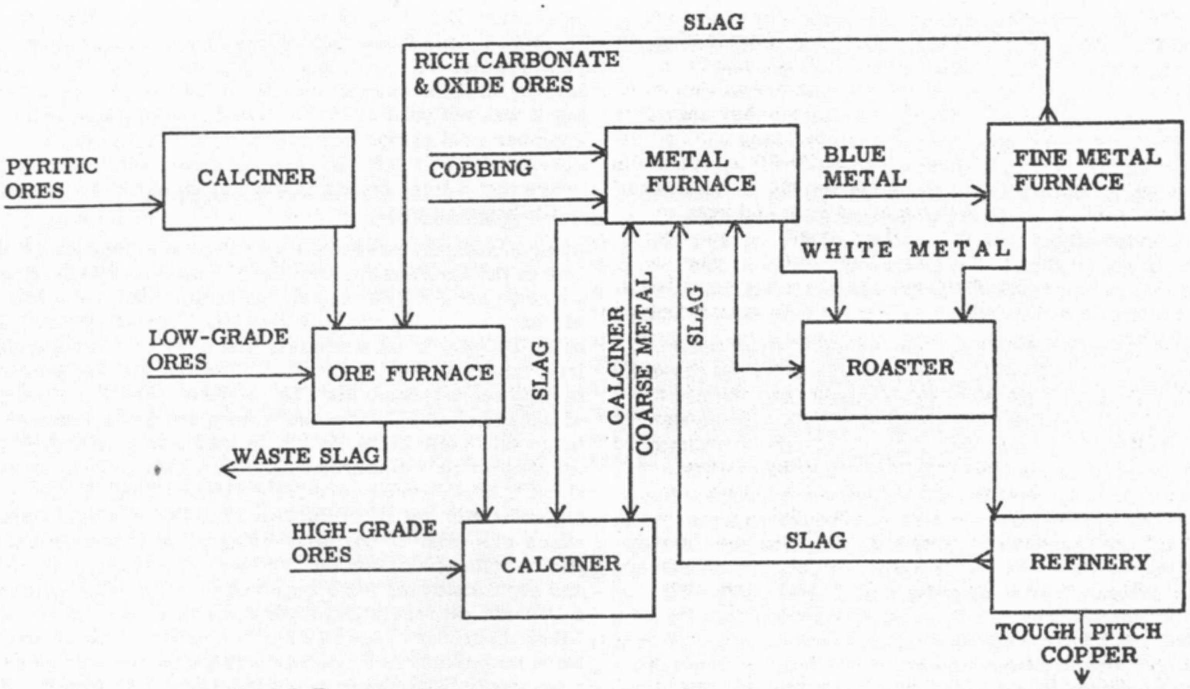

Fig. 1 — Flowsheet of Welsh Process

to form Cu_2S with all the Cu and FeS with an equal quantity of iron. The aim was to produce such a feed material for the second stage that the product would approximate to 35% Cu, 35% Fe, and 30% S after melting and slagging. Roasting of 3 or 4 tons in a reverberatory furnace 20-30 ft long by 10-12 ft wide, having a flat firebrick hearth, took 12-24 h. Care was taken to avoid sintering and fusion by keeping the temperature at about 800°C. The product was quenched in water to cause further breakdown of particle size.

The product of the first calcination was then mixed with low-grade (2-20% Cu) ores, free from excess iron, and slags from furnaces producing white metal (q.v.) in later stages and smelted in the ore furnace to produce coarse metal and slag. The furnace hearth was smaller, about 14 ft × 10 ft, and the hearth was about 20 in thick of silica sand. The ratio of firebox area to hearth area was about 1 : 4, compared with 1 : 11 for the calciner, and the temperature of operation was about 1150°C. Actual products ranged in composition between 21% and 40% Cu, 33% and 36% Fe, and 45% and 25% S. They were either granulated in water or crushed after solidification. The slag was brittle, dense, and black, with quartz particles from the hearth. A typical analysis was 60% SiO_2, 28% FeO, 3% Al_2O_3, 3% CaO, and 0.5% Cu, and it was sent to waste. In certain cases a richer matte, containing about 48% Cu and described as red metal, was produced. Copper oxide and copper silicates in the slags from later stages were converted into Cu_2S by reaction with FeS in the calcine.

This material was still of too low a grade for the production of blister copper with reasonable efficiency, and it was mixed with rich sulphide ores (25-45% Cu), low in iron, and calcined so as to reduce the sulphur content from 30% to about 16%. This again involved processing for about 24 h, starting with a charge of about 2 tons.

In the fourth stage—'running for metal'—the aim was to produce white metal (virtually pure Cu_2S) by smelting the calcined coarse metal with rich oxide and carbonate ores, blister furnace and refinery slags and such recycled materials as broken furnace bottoms and ladle linings and used bricks which were saturated with copper and copper compounds. If calculations were accurate, the product contained 70-77% Cu, 0.5-5% Fe, and 20-25% S. The slag contained 20-35% SiO_2, 45-55% FeO, and 5-15% Cu. This furnace had to operate at over 1200°C, and the availability of Dinas silica bricks after about 1790 must have greatly lengthened furnace lives. When either the oxide ores were not available or oxidation in earlier stages was not complete, a product described as blue metal was produced. This was a poorer product and one analysis gave the composition as 57% Cu, 16% Fe, 23% S. It had to be given an additional oxidizing smelt with slags in the fine metal furnace, in order to bring it to within the white metal category. The initial charge was about $2\frac{1}{2}$ tons and the fluxing requirements were met by reaction with sand on the furnace bottom. The product was cast into pigs in a sand bed.

The next stage was termed roasting by the operators of the Welsh Process. Pigs of white metal were stacked in the furnace so that there was maximum access of air from the firebox and from additional ports, and they were slowly melted. This took about 8 h and there was sufficient oxygen injected into the system that the reaction

$$2Cu_2O + Cu_2S \rightarrow 6Cu + SO_2$$

took place almost to completion; SO_2 evolution was promoted by a cyclic variation of temperature. The bath was heated and then allowed to cool until craters were formed in the pasty skin of copper, as a result of SO_2 evolution. This was repeated several times, accompanied by the removal of slag by skimming. The blister copper was cast into pigs, the composition ranging around 97-98% Cu. The slag contained 25-48% SiO_2, 28-32% FeO, 17-45% Cu_2O, and 1-2% Cu. This was returned to the fourth stage where the copper was recovered and the oxygen used to oxidize iron and sulphur. If SO_2 elimination was not carried out according to schedule, a lower-grade product, pimple metal, was produced; it was so described from the surface appearance when cold. This contained 89-96% Cu, 0.3-2.3% Fe, and 0.4-2.5% S and it had to be retreated before refining.

The final process of refining took about 24 h, and this length of cycle has persisted almost to the present day. Again the maximum absorption of oxygen was promoted by melting the piled blister bars slowly with free access of air and by 'flapping' the surface of the metal bath with rabbles, so as to cause splashing. The character of the slag changed during the oxidation period of 12-15 h, from low-surface-tension liquids requiring the addition of sand to thicken them before they were 'pulled' off, to oily separated pools of virtually pure Cu_2O. This last state was only reached when the bath was saturated with oxygen, the actual content being about 1%. The attainment of this condition was confirmed by pouring either small sample bars about 1 in square by 3 in long, or taking hand-ladle samples about 3 in dia. In both cases the correctly oxidized metal should cool with a deep central depression and should fracture to reveal a coursely crystalline dark red surface. After this liquid Cu_2O had been thickened with sand and pulled off, the surface of the bath was covered with either charcoal or low-sulphur anthracite coal and deoxidation was started by immersing one end of a 'pole' of wood, about 9 in diameter by 20-30 ft long. This caused extremely violent agitation of the metal, as a result of the evolution of hydrocarbons and steam and reaction between the wood and oxygen in the copper. As poles were consumed, the charred ends were allowed to float on the surface of the molten copper, so as to continue deoxidation, or at least to prevent reoxidation by the furnace atmosphere.

Samples similar in form to those described earlier were taken and examined before and after fracture. As the oxygen content diminished and the hydrogen content rose, the depression in the centre of the solidified sample disappeared and the surface became flat, with a characteristic wrinkled pattern. The fracture changed to a fine silky texture and the colour became lighter. The final test was to hammer the sample flat and then bend it over double and hammer it flat again. There should not be any cracking after this test. This product was described as 'tough pitch' copper and the oxygen content was 0.02-0.04%, depending on the other secondary elements present. If poling was carried out for too long, the solubility of hydrogen increased very considerably as oxygen was removed, and a 'worm' of copper was extruded through the frozen crust of the sample, as a result of gas-bubble formation in the last stages of solidification. Casting took a considerable time, because hand ladles holding about 56 lb of metal were used to transport the 8-10 ton charge. Refinery slags could be as much as 65-70% Cu, and one quoted analysis was 47% SiO_2, 2% Al_2O_3, 36% Cu_2O, 3% FeO, 9% Cu metal.

Modifications of the process included smelting for coarse metal and then making blister by reacting this with raw ore and burnt pyrites: smelting directly for blister by using large quantities of oxide and slag with the ore; and the direct process, in which a given weight of white metal was smelted with twice this amount of calcined white metal to make blister. The exact mixtures were found by experiment and in the direct process there was very vigorous SO_2 evolution. Arsenic and antimony were removed by making slags containing NaOH and CaO.

There was also the best selected process in which there was partial oxidation of white metal, leading to the formation of some copper, before the furnace was tapped. The first ingots cast had copper bottoms containing all of the gold, but only part of the silver, together with all of the Sn and Bi and much of the As and Sb. These were either electrolysed or made into $CuSO_4$ and the precious metals were recovered in the slimes.

Electrolytic refining on a commercial scale was first used by Elkington at Burry Port in 1869 and was readily adopted by the Swansea smelters for gold and silver recovery. As might be expected, there were considerable problems of slag disposal, ash disposal, and atmospheric pollution by furnace smoke and SO_2. The slag and ash were dumped in the lower Swansea Valley and on nearby hillsides, but only a small amount remains, thanks to the post-1945 demand for fill for factories, housing estates, and road building. The smoke and SO_2 destroyed all of the vegetation over a large area to the NE of the works and even 150 years ago there were those who protested at the desecration of the countryside. The principal copper smelter, J.H. Vivian, invited Michael Faraday in 1812 to advise him on a remedy but it was not until 1865 that Gerstenhofer calciners and a chamber acid plant were combined to confine the SO_2 and convert it into sulphuric acid. It is only within the last ten years that a firm growth of vegetation has been established in the blighted area.

Many arguments have been put forward to explain the decline of the Swansea industry after about 1855, including the wickedness of copper miners in Chile, Cuba, Peru, and Montana in setting up their own smelters. The most probable appears to be a combination of factors inseparable from monopolies. The manner in which ore was paid for in Swansea was such that the producer was at the mercy of the smelters. Deductions for smelting charges were large, and even the method of weighing was such as to put the shipper at a disadvantage. For a long period, up to about 1850, there was ore from Cornwall and Anglesey together with ore from Cuba and North and South America which was 'tied' by virtue of loans made to the mining companies. The maximum secrecy was practised by the smelters, and key employees were required to enter into restricted covenants with their employers. Orders for copper were filled according to the rules of the producers, and prices were maintained in a manner only possible when there is a monopoly. The imposition of an import duty on copper ores and blister copper in 1842 only served to worsen the position of the mineral producer.

The establishment of copper smelters near to the mines, from about 1820 onward, provided the alternative supplies which ultimately ended the Welsh copper trade. Smelters in Chile, Peru, Cuba, Australia, the United States, and Germany very quickly utilized, adapted, and improved upon the Welsh Process, the essential information in many cases being provided by Welsh emigrants. The development of large reverberatory furnaces capable of smelting 1000 tons of ore a day is attributed to Richard Pearce, formerly of Swansea. Large water-jacketted blast furnaces were constructed and, almost coincident with the invention of the Bessemer process for steelmaking in Britain, Kelly was making blister copper from matte, at great speed and without fuel in a silica-lined converter. It is almost axiomatic that unwillingness to share knowledge is paralleled by a resistance to use information from outside. This was the attitude of the Welsh copper smelters and, like other organisms which did not adapt to changing conditions, they became extinct.

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CONFERENCE PAPER

Some aspects of fieldwork in 16th century industrial history

D.W. CROSSLEY

British industry in the 16th century provides a number of interesting case-studies in the inter-relation of technology and the market. Briefly, in this period certain parts of the community increased their purchasing power, leading to growth in sales of durables and a gradual development not only of larger-scale processes, but also improvements in the quality and range of products. This in fact produced a feed-back, with the greater attractiveness of materials such as the improved glass and ceramics of the period or the utility of a material such as cast-iron having an influence on the growth of sales. While aspects such as these may appear to be the province of the economist, the historical material from which conclusions may be drawn derives from a variety of sources, documentary and archaeological. The latter have a contribution to make, owing to the poor survival rate of records from the relatively small-scale industrial concerns of the period, many of which indeed kept only the most rudimentary of accounts in the first place. It should however be stressed that the archaeological approach is frequently a laborious one, and there are many questions which a good set of accounts answer not only more rapidly, but also to better effect. On the other hand, there are points of yield, technique, or product quality which are unlikely ever to be answerable from the written business records or correspondence of the time. This paper indicates (and in its form for the conference illustrates) certain areas where information from written contemporary material and from fieldwork can be complementary.

I

Two industries, iron and glass, offer themselves as examples for this approach. First should be stated, in brief outline, the technical changes which occurred. In iron making the bloomery gradually passed out of use, superseded by the blast furnace and finery forge; the important points are the change in the scale of the producer units and, of rather less significance, the appearance of a new material, cast iron. In glass-making, outside the field of this Group but a useful parallel, technical changes were less obvious, but during the second part of the 16th century a series of small developments led to major savings in costs and a marked improvement in the quality of the glass made; changes in furnace design seem to have been the main factors involved, coupled with a developing knowledge of raw materials.

This outline, briefly stated, should be amplified after some discussion of the changes in the market which encouraged such developments. During the 16th century certain groups within the agrarian and urban communities were in a position to increase their real incomes, and their patterns of purchasing reflect this. Rising population in general and a growing urban population led to a strong demand for foodstuffs, in particular in the south-east around London; the London food market's catchment area stretched further and further beyond the Home Counties, and an increasing number of farmers found that they could sell both arable and pastoral products to wholesalers from the capital. Beyond the south-east demand may have grown more slowly, but the developing towns of the West Midlands and the West Riding are other examples of the pull on agricultural production. The beneficiaries of these developments were mainly farmers and landowners whose methods and management were astute enough to keep their incomes ahead of the rising rents and prices of land, the price of food and, to a lesser degree, of durables. It is among this section that the growth in demand for materials such as iron, textiles, glass, or ceramics was significant. It is only fair to say that there was a large group lower in the scale of incomes whose prosperity did not grow; indeed, the buying-power of the wage of the labourer, in particular in towns, fell severely during the 16th century. In spite of the latter point, the gross consumption of durables seems to have been raised by this particular distribution of incomes; sales of such goods among the labouring population had anyway probably been small in the 15th century, for the acquisition of a plot of ground had always been highest among the spending preferences of the landless. Further, in addition to the consumption of farmers and landowners there was increasing wealth among traders and townsmen, whether directly or indirectly involved in food supply. Both in country and town there was a general trend to the improvement of standards of housing and comfort among the relatively affluent, and the element of fashion involved in such standards tended to accelerate the process.

That the market for durables was a thriving one is made clear by numerous sources. The houses of the period are perhaps the most obvious indication; at the top of the scale the styles of architecture in vogue at the end of the 16th century involved the use of increasing quantities of glass, iron, and lead as windows grew larger and their fittings more complex. Housing of any style required more iron, whether nails for roofing, or iron for casements, fasteners, locks, or hinges; whilst the typical 16th-century farm house of midland and south-east England may have been scarcely affected by the styles of the great country houses, the sheer volume of vernacular building cannot have failed to affect demand for materials. References to new houses are commonplace, and just as significant was the trend towards improvement of existing buildings by addition of partitions, floors, windows, and outshuts. Probate inventories, by listing contents of houses room by room, illustrate the tendency and provide some indication of the opportunities for the use of iron in particular. Such inventories show the extent of the market elsewhere in the agricultural scene; in lists of implements are indicated the growing use of iron in ploughs and carts, as the opportunities for agricultural profits fostered increasing capital expenditure on equipment that would promote greater efficiency. Corresponding with this trend are the growing numbers of tradesmen such as ironmongers or glaziers. In the larger provincial towns such as Leicester or Exeter they have been shown to have had an increasing prominence. This does not seem to have been restricted to towns of such size; village smiths were in just the position to profit from the growth in the use of iron in their neighbourhoods, as were the glaziers of comparatively small market towns.

II

The pull exerted on industries of the period can be shown to have been significant; it should, however, be pointed out that the evocative terminology of 'industrial revolutions' used by earlier historians is a confusing one. Demand may have exceeded anything seen in the medieval period, but there was no real mass market, nor was there any export-led boom in a manufacturing industry as seen in the 18th century. Whilst the coal industry may indeed have undergone a massive percentage growth at this time, iron, glass, non-ferrous metals, or ceramics must be seen developing on a scale that was more slight but nonetheless of interest. Indeed, they pose the question of at what stage a gradual market growth encourages technical change in industries using essentially medieval methods.

Iron provides an outstanding example. The blast furnace had been developed on the continent from the high bloomery by a process of evolution; in England, by contrast, the high-shaft type of bloomery had not been used after the Roman period, and the bowl hearth had reached the end of its development, producing perhaps 25-30 tons of wrought iron in a year in its most up-to-date water-powered form. There was therefore a very real technical jump to be made by English iron producers, who had, it seems, no experience of shaft furnaces; in addition, the blast-furnace process, apart from any technical problems, real or imagined, posed considerable logistic difficulties. Not only did it operate on a larger scale, but it also required to be run over long periods. It need hardly be stressed that discontinuous operation would be uneconomic, and that campaign length was all-important in reducing the cost per ton of iron and the cost of hearth-building and in reducing the frequency of what at first seems to have been a thoroughly troublesome operation. To replace the discontinuous operating pattern of the bloomery with campaigns of 15 or 20 weeks or even more meant ensuring a reliable raw-material supply of consistent quality and price. With ore pits of small size a change of supply could, without foresight, occur in mid-campaign, perhaps causing problems if variations in the quality of ore took place. Charcoal could equally cause difficulties; if supplies from one wood were to run out, transport costs from alternative sources could be a significant problem. It would perhaps be over-pessimistic to fear that such supply problems might often occur in mid-campaign, but over a few years of a furnace's life big changes certainly could happen, threatening the return on an investment of a scale much higher than that involved in the bloomery.

Thus there had to be incentives to set up the new process, sufficient to outweigh the factors spelling caution; in particular there had to be a market for a quantity of wrought iron, perhaps six times as great as from the bloomery. Whilst for the large landowner this might be no particular problem, with the rationalizing of the production of several bloomeries into a single unit, the tenant ironmaster with a single bloomery was more likely to have to explore the chances of selling a large increase in output, if he changed his plant. In the light of these considerations the spread of adoption of the blast furnace is of considerable interest. In the Weald, furnaces appeared slowly between 1496 and 1530, with a great increase in the rate of building in the next 30 years, to 1560. Little in fact is known about late bloomeries in this area, but such fragmentary information as there is ceases in the middle of the century. What is perhaps important is the period of overlap between the two processes; in the West Midlands this, in outline, occurs in the period 1560-90, and in South Yorkshire between the 1580's and the 1650's. This corresponds with what we know of the market, for agricultural prosperity came earliest to the Home Counties and the South Midlands, and the connection is underlined by taking an extreme case, that of the Furness area, where the new process was only introduced towards 1700, into an area where the development of demand would clearly be far less rapid.

This brief outline of innovation can easily be derived from documentary sources. It is when the need for refinement arises that fieldwork may be useful. Two questions may be taken as examples, although others will no doubt occur to many people. It might be asked, firstly, how far the mechanization of the bloomery had progressed by the 16th or early 17th century, and whether the maximum potential of the process had been reached in a particular area at the time of local introduction of the blast furnace. Secondly, it is of some importance to look in detail at the rate of development of blast-furnace technology in its early stages, to see whether any significant improvements were achieved in, say, the first century after introduction into Sussex in 1496.

On the first point, while it might be assumed from published work that powered bellows and hammers were a common feature of bloomeries by the 16th century, excavation at Rockley (Yorks. W.R.) has shown this not necessarily to be so. Whilst at this site the bellows for bloom-hearth and string-hearth were operated by water wheels, there was no evidence that the hammer had been thus powered. This site was rebuilt in the form excavated in about 1600 and worked until 1640. It was completely undocumented, and the scale and dating were established entirely by excavation, at a site with no above-ground remains. The potential for recovering a comprehensive view of such a site, indicated by the Rockley excavation, focuses attention on the problems of the bloomery period in the Weald. Here, while the chronology of the introduction of the blast furnace is clear from written sources, the state of development of bloomeries is not. The only information available concerns four sites: one at Tudeley (Kent) working on a manually-powered basis in the mid-14th century; a bloomery, not precisely located, near Roffey (Sussex) in the early 15th century; and two sites referred to as forges, near Frant (Kent) in the 1520's, and too far from extant blast furnaces easily to be accepted as fineries. There is clearly a need for exhaustive field investigation of sites such as these latter and, further, careful examination of all early Wealden sites documented in the early or middle 16th century as fineries but perhaps originally bloomeries. It is the possibility of a conversion of functions which makes careful excavation essential, particularly as confusion between bloomery and finery cinders and, in particular, furnace bottoms is not impossible on casual inspection.

The second point, the development of the blast furnace, requires a series of examinations of closely-dated early sites. A start has been made with work at the furnace of 1542 at Panningridge (Sussex). Here a surviving building notebook and comprehensive accounts can be correlated with a site where the furnace foundation, the bellows area, casting beds, and a substantial fragment of a water wheel survived beneath demolition debris and material associated with a later furnace, whose date of building is problematical but whose destruction occurred well before 1611. Here it is of value to make comparisons between two essays in early furnace operation which can hardly be more than two or three decades apart. It is hoped that amplification of the picture will come from current excavations at Chingley (Kent), where tenuous documentation shows a furnace to have operated in the 1560's, to have been derelict in 1588, and (probably) to have been refurbished in the mid 1590's for a life of unknown length. Clearly, the next stage must be investigation of one of the really early Wealden sites, although later disturbance and re-use present severe problems.

A good deal of caution must, however, be expressed about the results of such work. In an area such as the Weald, where furnace structures were inevitably used as stone quarries after abandonment, the survival of more than the footings or of the lowest part of the hearth is unusual, and the absence of the third dimension is a serious problem. Whilst the ground plan may be recovered, its usefulness is rather limited. The survival of timberwork, however, is more frequent, for in valley-bottom sites preservation of wood is common when the water-table has remained high, as the surviving proportion of the wheels of each Panningridge period show. This gives the opportunity for calculating the potential power output of water wheels, indicating the requirement of the furnace to some degree. Furthermore, the layout, the type of wheel involved, and the head of water required can all be established. In gauging the efficiency of extraction there are difficulties; in theory, the ores, slags, and cast-iron runners, the relevant debris, are commonly found, with occasional fragments of actual pigs. However, the problems of sampling are obvious; ores from neighbouring natural deposits are safer subjects for analysis than material, perhaps rejected, found on site; the variation in slag composition can be considerable, and the chances of cast-iron runners being atypical are high. Too much, therefore, should not be read into figures from small numbers of samples; this point cannot be put too often or too forcibly.

While attention is apt to be concentrated on bloomery and blast furnace in this early period, the finery forge should not be ignored. Conversion of pig to wrought iron does seem to have posed problems in the Weald early in the 16th century, despite accumulated experience in the 15th century on the Continent. It is worth noting that castings seem to have predominated at the first furnaces, largely for military needs, with cast ammunition obviously the major product. However, furnaces and fineries, in combination, were being planned and erected by the mid-1530's, but a good deal of experiment seems to have been needed to improve yields. The conversion ratio of 2 : 1 at Newbridge in 1539 should be compared with the 3 : 2 which became predictable enough at Robertsbridge by 1550 to be made a standard basis for accounting. Little work has been done on the early finery, although information may emerge if it proves feasible to work on the bloomeries which were rebuilt as fineries. It is, however, important to establish the scale of the purpose-built finery of the late 16th and perhaps early 17th century, and the forge site at Chingley, currently under excavation, goes some way towards this. Already a good deal of information has come from this example, although how far it is typical can only be decided after further sites have been seen. It is sufficient at present to say that many of the constructional and maintenance items in the Robertsbridge Forge accounts of 1541-74 have been clarified by features at Chingley, an early 17th-century example.

III

We have, then, indicated how the historian's apparatus for examining industrial change may be widened by fieldwork. On this level it may be useful to look for illustration elsewhere in the industrial scene of the 16th century, but in a way which is also useful in developing the ideas of interaction of market and innovation referred to above. It has been seen that introduction of the blast furnace to a large extent awaited market development, and only to a small extent was there a new product, in this case cast iron, which would help to generate further demand. With non-ferrous metals the pattern varies little. Humphrey's methods of smelting lead created no new version of the product, but assisted producers to meet the demands of the building industry; similarly, immigrant techniques of copper mining and brass and wire manufacture, whilst new to this country, provided materials traditionally in use and hitherto imported. However, with glass there is a difference and a parallel to the influence of cast iron as a new product. This may be briefly examined and illustrated.

English medieval glass-making took place on a small scale, in particular in the western Weald and in Staffordshire. The vessel and window glass produced was of indifferent quality, being prone to surface lamination due to weathering and being at best translucent rather than transparent. There was, nevertheless, an established market, and it was to this that the Antwerp entrepreneur Jean Carré was attracted in 1567. He organized the construction of furnaces in the Weald and in London, and the supply of French craftsmen to operate them. The new industry developed over the next 30 years, numerous foreign glass-makers setting up furnaces in Sussex, Hampshire, Gloucestershire, Staffordshire, and the North Riding of Yorkshire. Their arrival shows the attractions of the English glass market, although many Huguenots were perhaps influenced by the comparative freedom of religious belief in England compared with the Low Countries. The achievement of the new industry was twofold; it provided glass which was cheaper in real terms than the English or imported glass of the early part of the century, and it produced a material of greatly improved quality. The price of glass fell, in money terms, over the period 1570-1610, while that of other manufactured products, iron included, continued to rise. The second point, of quality, shows very clearly when excavated glass of the late 16th century is compared with that of 1500-40, and it is obvious that a more attractive product would have had some effect on total sales, perhaps diverting buyers from other container materials, or taking a growing share of the new purchasing power of landowners and farmers. This indeed is analogous to the position of cast iron. How these improvements in economy and quality were achieved is less simple to explain. Furnace design certainly changed, with a greater elaboration and the use of one fire for more than one stage of manufacture; further, the relative absence of inclusions in later glass suggests better selection of materials. It is only from field evidence that this impression of improving quality can be gained. These impressions dovetail well with documentary information on prices.

There is clearly further scope for this approach if resources can be found to continue work of such a kind. In particular, the developments in lead smelting of the second half of the 16th century should be examined, and it is worth speculating as to the extent of improvement in methods in tin and copper over the period.

Errata

In Vol. 4, No. 1, 1970, p. 26 in the second paragraph, the word 'presence' should have read 'absence'.

In the last issue, Vol. 4, No. 2, 1970, in the summary of George Parker's lecture, 'A metallurgist looks at the Bronze Age', a sentence in the final paragraph on page 74 should have read:

'Wells Museum possesses a modern casting of a winged and looped palstave made in such a bronze bivalve mould now in Hull Museum'.

In the same issue, on page 87 in the abstract of the paper by Laissus, for 'white iron' read 'tinplate' in both cases.

In the paper by G. W. Henger (Vol. 4, No. 2, 1970), on p. 46, there is a discrepancy in the values for phosphorus content of Specimen N3 between the caption to Fig. 1 and Table I: the correct value should be <u>0.08%</u>.

Smelting in Perthshire: a quest for copper

J. W. BAINBRIDGE

Between 1838 and 1862 small irregular deposits of pyrites were worked by John Campbell, second Marquis of Breadalbane, at Tomnadashan on the southern side of Loch Tay in Perthshire.[1] Today, samples of slag are easily found among the pebbles at the edge of the loch, 400 m below the former mine workings, indicating that there had been smelting of some description.

Two decades after the mine had been abandoned, Wilson and Cadell reported that Tomnadashan ore had been dressed and smelted in works erected on the shore of the loch.[2] More accurate and fuller details of the smelting that took place are, however, available in the unpublished Breadalbane Papers housed in the Scottish Record Office, Edinburgh and these have been drawn upon in the following account.*

In the early years of mining at Tomnadashan, an interest had been shown in smelting the ores locally. A letter to the Marquis of Breadalbane from one of his advisers, Professor Lewis D. B. Gordon, of the University of Glasgow, suggested that the ores should be stockpiled at or near the mine until it was decided what should be done with them. In this correspondence of 16 March 1841 (box 4), Gordon indicated that Odernheimer the mineral prospector was anxious to smelt. However, there were no further developments until 5 March 1843, when Breadalbane received details of Swansea copper smelting (box 1).

FURNACES AND FUELS

Extracting copper from its ores in the mid-19th century was a tedious business and required large amounts of fuel. The Swansea process, in which Breadalbane was interested, employed at least six distinct stages with the ore being calcined, melted, calcined, melted, roasted, and refined in reverberatory furnaces. Details and variations of the process are found in general metallurgical works of the 1850 and 60s.[3] According to Overman 20 tons of coal were needed in 1852 to produce 1 ton of copper from sulphureous ore containing 9% copper.[4] Nine years later, Percy gave a general figure of 13 to 18 tons of coal, costing 5s. per ton in South Wales, as the fuel needed to win 1 ton of metal.[5]

The location of Tomnadashan relative to a coalfield was therefore crucial if Breadalbane hoped to smelt competitively on Lochtayside. The distance between the nearest source of coal and Tomnadashan ore was fully appreciated by the Rev. Alexander Stewart when writing about Killin parish in the New Statistical Account in 1843.[6] Because of the excessive conveyance charges, coal at £1 10s. per ton was twice as costly in Kenmore as in Perth in 1838.[7]

CHARCOAL FUEL

An answer to the high cost of coal might have been to use charcoal in a blast furnace. The Taymouth Castle estates had been improved over many years[8] and there was a plentiful supply of local timber.[9] Among the Breadalbane Papers, however, there is an undated questionnaire (box 1, document 2), with answers provided by Breadalbane's factor, Wyllie, which suggests that fuels other than coal might have been considered.

Charcoal was manufactured on the estates but the annual output never exceeded 20 tons and this was not put to any metallurgical use. Wood, at 10s. a ton, was carbonized in lazy kilns and 4 tons were needed to produce 1 ton of charcoal. Thus, if Wyllie's costing of local timber is accepted, charcoal at £2 per ton was appreciably more expensive than imported coal. This simple deduction may account for Wyllie's answer that he did not think there was any fuel that was cheaper than coal. Also, when considering which fuel might be used to reduce the ores, notice would almost certainly be taken of what was achieving good results elsewhere in the United Kingdom. Would not coal be favoured by an owner not unduly concerned with expense?

THE FURNACE BUILDING

Sixteen years separated Breadalbane's enquiry about smelting ores and his decision to authorize the building of the furnace. His reluctance to attempt to smelt Tomnadashan ores may have been overcome by the stockpiling of ores that had taken place over nearly two decades.

In a report of 1 August 1859 (box 4), the mines manager, Gustavus Thost, informed Breadalbane that the ground was being prepared for a double furnace of the following dimensions:

Smelting area $(11 \times 4\frac{1}{2}\text{ ft}) = 49\frac{1}{2}\text{ ft}^2$

Fireplace area $(4\frac{1}{2} \times 2\text{ ft}) = 9\text{ ft}^2$

The proposed furnace was thus considerably smaller than the Swansea furnaces of a similar type that had corresponding dimensions of $71\frac{1}{2}\text{ ft}^2$ $(11 \times 6\frac{1}{2}\text{ ft})$ and 14 ft^2 $(4 \times 3\frac{1}{2}\text{ ft})$. Then on 28 November 1859, Thost reported building to be in progress (box 4) and five days later Robert Baldie, clerk of works to Wyllie, stated that the furnace bars had been laid and the flue lined as far as it had been dug (box 4). The boat from Killin had that day discharged bricks, fireclay, and iron. Baldie also indicated that the furnace builder in Glasgow was ready to travel to Lochtayside.

In a third progress report for 18 to 26 December 1859, Thost told of the bricklayers being at work. By 3 January 1860 they had brick-lined the smelting hearth and first arch (box 4). This fourth report from Thost, of 3 January, also informed Breadalbane that the sailing boat was not suitable for transporting their materials and they were 'coming to terms with the Potatoe-Milk boat' (box 4, document 65). Thost expected the furnace to be completed by the end of the following week and included in the fourth report an admirable freehand sketch (Fig. 1). The furnace, similar in design to some then operating in the Swansea area,[10] had an upper calcination hearth and a smelting furnace situated beneath it, so that when in use ore was passed from the upper hearth to the furnace below.

However, building the furnace did not progress as planned for on 2 February 1860 Thost broke the news to Wyllie that the arches in both the calcination and smelting hearths had sunk and requested that the bricklayers' wages be withheld until the cause was ascertained (box 4). A note added to this letter and dated the next day said that all brickwork would have to be done again. The following day, 4 February, Thost wrote to the second Marquis informing him of the mishap that had struck Tomnadashan just as smelting was about to begin (box 4, document 67). Breadalbane obviously took control of the situation at this point for, when Thost wrote to him on 16 February 1860 telling of the arrival of the Swanseamen, who 'had been at Chili for a similar purpose', he added that 'Mr. Wyllie has informed me of your Lordship's plans as to how to proceed for the rebuilding of the arches' (box 4, document 69).

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* A full inventory of the Breadalbane Muniments is not yet available and access to it is by means of a handlist which indicates the main classes of documents and covering dates. As for the papers relating to mining, all references were located in boxes of Section 18 of the Collection. Each reference will be acknowledged in the text by quoting the number of the box in which the document is kept and the provisional number a document may at present possess.

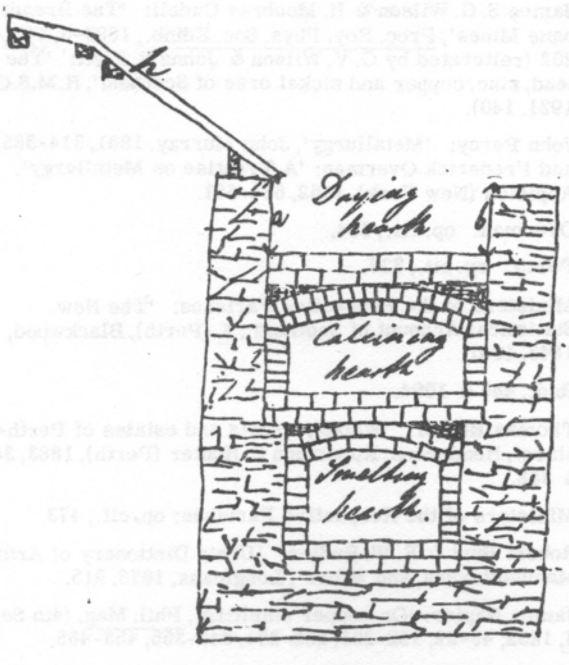

Fig. 1 — Thost's freehand sketch of the Tomnadashan smelting and calcining furnace. The drawing contains the following note: "The pieces a and b will now have to be added as a kind of parapet upon the support walls to serve as a receptacle for the ore which falls upon this, the drying hearth, by means of the hopper h."

THE FURNACE SMELTING

Two months were required to repair and complete the furnace and on 28 April 1860 Thost informed Breadalbane that the furnace was being tested and that 23 to 28 April should be considered 'a week of grace' (box 4). Then in the following week (30 April to 5 May) 306 cwt of coal melted the following:

220 cwt	of stamped ore
312 cwt	of dressed ore
44 cwt	of lime
576 cwt	of stuff

Thost further reported that the furnace worked well and had produced 136 cwt of regulus from the 576 cwt of stuff.

Similar returns for the furnace were recorded in the next progress report of 19 May 1860 (box 4, document 80), when Benjamin Gribble informed his master that 'the smelting furnace appears to work very well', the performance of the previous fortnight being

Week ending		12 June 1860	19 June 1860
Smelted:	dressed ore	17 ton $7\frac{1}{2}$ cwt	18 ton $5\frac{1}{2}$ cwt
	undressed ore	12 ton	11 ton 5 cwt
	limestone	2 ton 2 cwt	2 ton 4 cwt
	total	31 ton $9\frac{1}{2}$ cwt	31 ton $14\frac{1}{2}$ cwt
Coal used		15 ton 16 cwt	?
Regulus produced		7 ton 11 cwt	8 ton $14\frac{1}{2}$ cwt

Smelting continued throughout June 1860 (box 4, documents 83-87) and a report from Thost of 25 June (document 85) described in detail the furnace at work, the high degree of efficiency that it was achieving, and experimentation that had taken place which would increase its output further. Calcination of the ores was being improved and Thost was intent on the smelters following a new order of working in order to improve the quality of the regulus. It was also proposed that the furnace could cope with five charges every 24 h instead of the usual four without using any additional coal. To enable this to be put into practice a bonus was to be paid to the men. The absent Breadalbane could perhaps be excused for believing that the Tomnadashan furnace was fast becoming an efficient unit. However, he did not accede to the request made by Thost, in the same report, for a furnace '10 to 13 feet in height and about 4 feet in width' to smelt regulus.

The next account to have survived (box 4, document 88), written by Gribble on 14 July 1860, indicated that the furnace had been in use up to that time but was needing repairs, and it would be a week or more before it would be cool enough to enter. This report also included a statement of the furnace's performance for the first twelve weeks that it had been in operation:

Smelted:	dressed ore	184 ton 14 cwt
	burned and undressed ore	125 ton 14 cwt
	calcined regulus	2 ton 9 cwt
	limestone	15 ton 5 cwt
	total	326 ton 2 cwt
Coal used		179 ton 5 cwt*
Regulus produced		85 ton 1 cwt

Did Breadalbane detect the error in addition made by Benjamin Gribble?

A YEAR'S LAPSE?

A report on developments at Tomnadashan, dated 25 June 1861 (box 4, document 86), indicated that James Napier, one of the leading authorities on copper smelting of the day,[11] had examined the potential of the site and reported favourably. Following this report, Napier took control at Tomnadashan (box 4, document 90) and smelting began again on 10 July (box 4, document 123). Whether the furnace had been idle for a full 12 months or for a shorter period has not been ascertained. Once restarted, the furnace worked satisfactorily but Napier was uncertain what was to be done with the regulus produced. Breadalbane was informed that to bring it to a metal would require another two furnaces. Napier advised against these being built on Lochtayside. Instead, he suggested that the regulus be sent to Swansea where 15 years earlier he himself had developed a copper smelting process.[12]

THE FURNACE ABANDONED

In James Napier's report for September 1861 (box 4, document 130) it was reported that there had been no smelting after mid-October for want of ore. Thus it would seem that the mine had failed and brought smelting to an end, but reports (box 4, documents 131 to 138) written by Gribble tell of ore being mined from December 1861 until 28 July 1862. This, however, was too late for the smelters, who had been engaged until mid-December: they had accepted moderate compensation and had left (document 130). The regulus was piled at Fir bush pier. Smelting on Lochtayside having lasted less than two years had ended.

POSTSCRIPT

Without the second marquis's resources and his desire to exploit minerals that did not exist in appreciable quantities, it is unlikely that the Tomnadashan furnace, like the mine,

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* Does not include the coal used to dry the furnace.

would ever have existed. Whether Breadalbane expected copper to be produced in the single furnace is a moot point. When writing in 1884 about Tomnadashan mine, Wilson and Cadell mentioned the great cost of transporting the metal when smelted to the Glasgow market.[13] They wrongly assumed that copper had been produced.

Perhaps the key to more successful smelting would have been a readily available supply of suitable fuel. The several hundred tons of coal used in the furnace had been transported with difficulty and at considerable expense. James Napier had also considered alternative fuels that might have been utilized on Lochtayside and in July 1861 (box 4, document 123) he contended that a new process to convert peat into a hard dry fuel could be used. Had this been realized, the efforts of the Welsh smelters and all who had been involved in the Tomnadashan venture might have provided a more metallic return for Breadalbane.

The regulus stacked at Fir bush pier had, according to Napier, a copper content at best of 18-20% as well as 12 oz of silver per ton (box 4, document 124). The furnace, while reducing the poor Tomnadashan ores was far from achieving pure copper.

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Excavation of bloomeries in Rannoch (Perthshire) and elsewhere

W. G. AITKEN, D. A., F.S.A.S.

This is a short report on various excavations of bloomeries, carried out during the past four seasons, and of work which is still being carried on at certain sites. It is not intended to be a full and comprehensive account, but rather a survey of the operations undertaken during the period covered.

THE SITES

No. 1: Bridge of Gaur

My attention was first drawn to a dispersed slag heap at Bridge of Gaur at the western end of Loch Rannoch in Perthshire by Miss Alison Cameron. (No. 1 on Table I and Fig. 2.) The site is on a flat-topped knoll with a large stream flowing past into the Loch, which lies about three-quarters of a mile to the east. On the north face of the knoll and very close to the right bank of the stream, I uncovered a large well built lime kiln. This structure is later than the bloomery, as slag from the site above it was found at the base of the kiln among the infill, and a quantity of the same material had been used to fill the 'backing' around the sides of it. This kiln was made the subject of a separate report.

The actual furnace was difficult to find, but I eventually uncovered the bowl and the surrounding stones. It is an extremely good example of its kind with a considerable amount of slag adhering to the sides and base of the 'bowl'—particularly thick at the western end where two large stones mark the position of the tuyere, and where the heat would be greatest. The 'bowl' is rectangular rather than circular and by the position of the stones surrounding it, some with slag adhering, had been cut out originally in that shape. A double line of stones extended west of the hearth, opening out in a fan or funnel shape and having a rough paving or cobbling of small stones within the area thus enclosed (see Fig. 1).

Although the whole top of the mound was covered with a thin layer of slag, disintegrated charcoal, and patches of dark red earth, no sign remained of the usual heap of slag. It could be assumed that the kiln builders had used the material and had probably scattered the rest in order to flatten the top of the mound for ease of walking.

TABLE I Hearths and Slag Heaps in Perthshire excavated or examined by the Author

Sites are identified by name, either descriptive or given locally to the immediate area. The numbers correspond to those shown on the sketch maps.
The map reference is also given.

Sketch map No.	Descriptive name	National Grid Ref.
1	Bridge of Gaur	NN 503562
2	Dunans	NN 485576
3	The Barracks	NN 457542
4	Upper Dall	NN 590542
5	Outer Dall	NN 597525
6	Lower Dall	NN 594554
7	Leagag	NN 504543
8	Red Stable, Glen Comrie	NN 465533
9	400 yd north of No. 8	approx. same
10	Station Road, Rannoch	NN 462574
11	The Greens, Outer Barracks	NN 445504
12	Comrie Hill	NN 482559 approx.
13	Comrie Hill	NN 482553 approx.
14	West Camghouran Farm	NN 559555
15	Coille Bhienie, Rannoch	NN 488576
16, 17, 18, 19	Part of same complex as Barracks above	NN 457542
20	Aulich, north side of Loch Rannoch	6" NN65NW or NN 606599
21	Balquidder, Ballimore Farm	NN 530170
22	North shore of Loch Voil, Balquidder	NN 48941984 6" sht. NN41NE
23	Stronachlachar, Loch Katrine	NN 399104
24	Grundd nan Darachan Rannoch	NN 470539

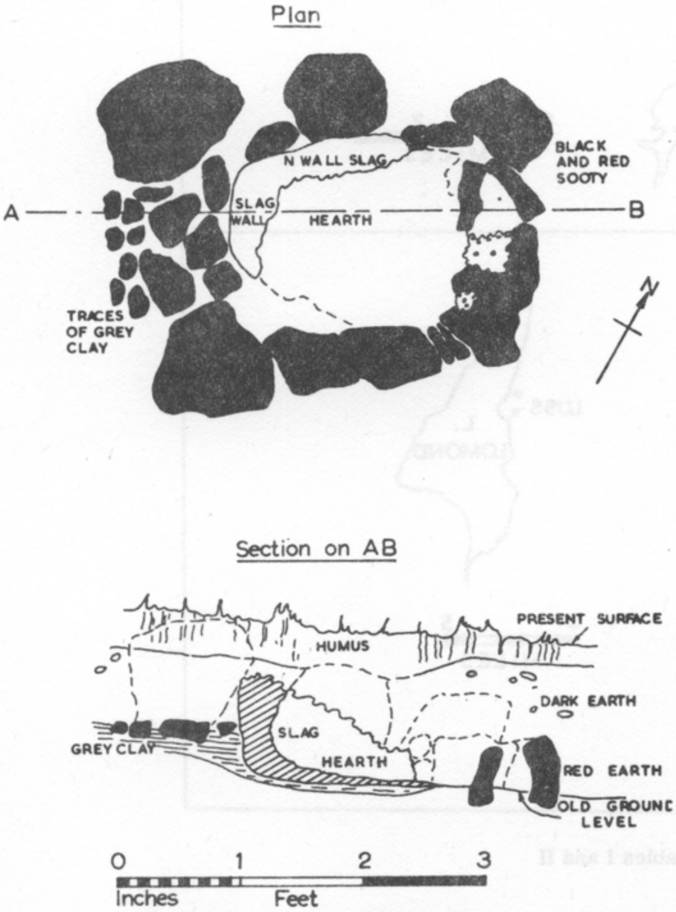

Fig. 1 — Smelting hearth at Bridge of Gaur, Perthshire; No. 1.

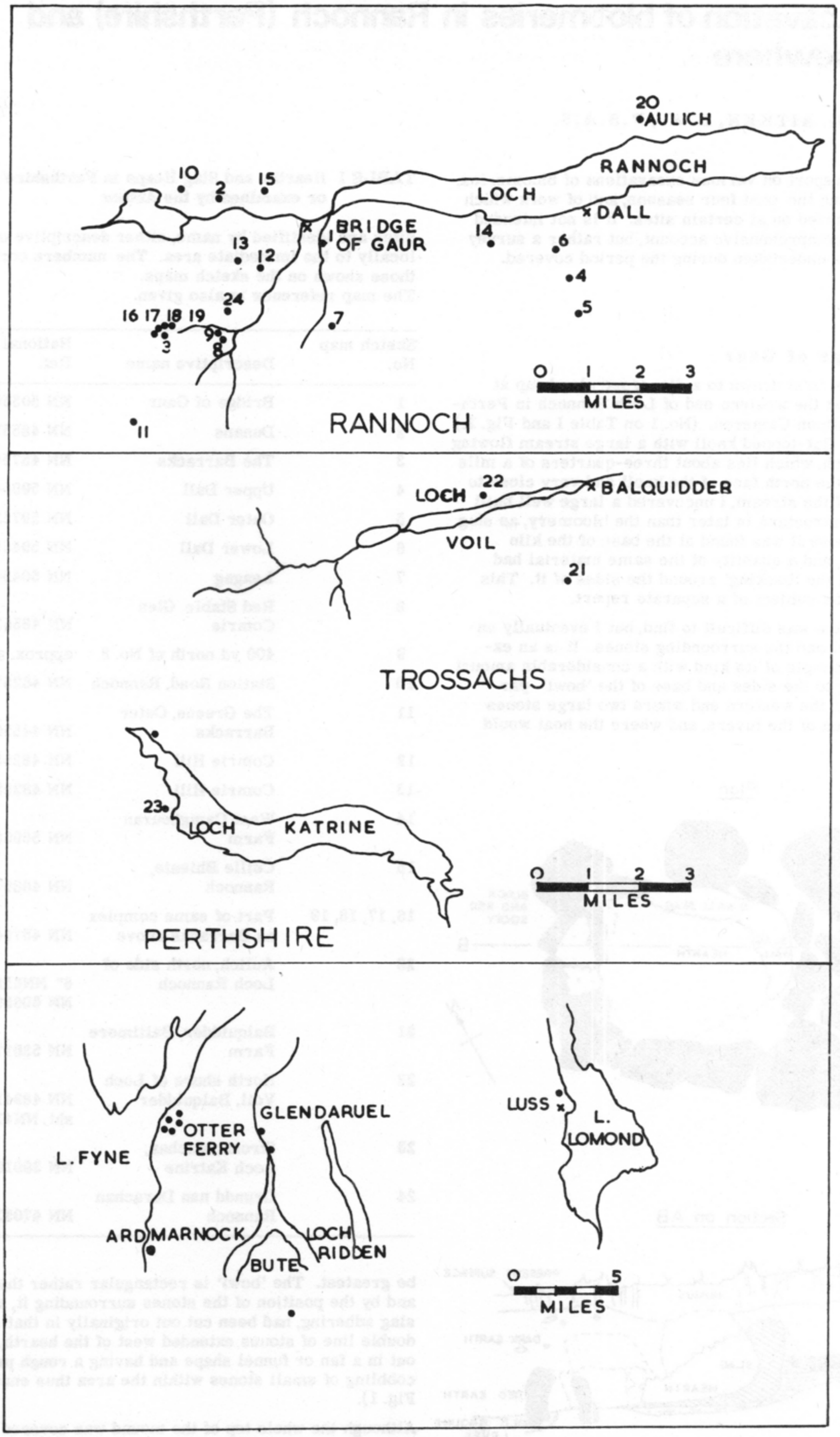

Fig. 2 — Distribution maps of sites mentioned in Tables I and II

No. 2: The Dunans, Bridge of Gaur

The staff of the Forestry Commission, on whose ground many of the sites lie, having seen site No. 1 uncovered, recollected certain areas where the large Forestry ploughs had passed over heaps of slag. As far as was possible, I examined and excavated the sites indicated. Many were irretrievably damaged by the great ploughs, and only occasional find of stones with slag adhering provided proof that a furnace had been in the vicinity. Site No. 2 was a case in point. Between two streams on a small sheltered valley some 300 yd to the north of the road to Rannoch Station and 1½ miles from Bridge of Gaur, the plough had torn right through the long axis of a very large slag heap. This heap, some 32 ft long and 22 ft wide, was the largest found in the Rannoch area. Composed of a vast quantity of reduced charcoal and slag, I had hoped that it would produce a good example of a hearth, but in spite of careful digging only an area of tap slag and some large stones were found, the plough having gone right through the hearth itself.

No. 3: The Barracks

The Forestry Commission, in the course of opening up the Moor of Rannoch, have driven several roads into the 'wilderness', and at the end of one of these 4 miles west of Gaur a complex of five heaps, close together, was found. Again the ploughs had scattered and broken up the mounds but part of a hearth was found intact at one point, whilst a fine piece of adhesion—slag on granite—was found among the 'scatter' of another heap. It might be fair to assume that there had been at least five hearths in this area. The part hearth had a flat 'slabbed' area formed by two large flat stones with a wall of large boulders at the east end. Behind this wall was an area of solid tap slag. A quantity of charcoal was found nearby and some pieces were sent away for identification. The west end of the hearth had been cut across by the plough.

No. 4: Upper Dall (Fig. 3)

Dall lies 5 miles east of Gaur, down Loch Rannoch and on its southern bank. To date four slag heaps have been found in the area and of these four No. 4 Upper Dall proved to be of great interest. The main feature was a platform of four large flat stones roughly 3 ft wide and 6½ ft long, ending in a rough semicircle of boulders, double-banked at the southern end. Beyond this wall lay areas of almost unbroken tap slag. No less than seven different layers could be distinguished. A number of large stones at both sides of the platform (disturbed by the plough (might indicate that the wall had been continued for a short distance northward. At the northern end two large stones were sunk into the earth, with a smaller oblong stone a little way from the gap between the two but on the centre-line. At the south end of the 'platform' there was a depression walled in on one side by the semi-circle of large stones. There was an area of adhesion within the depression. Several patches of slag adhesion were noted on the surface of two of the large flat platform stones. The tap slag had been poured southwards around the base of the wall, and a number of the wall stones were enclosed at their base by the slag. There was no great heap of slag, as most of it had found its way into a small valley beyond. To the west of the site, at a distance of 20 yd, a number of large stones marked the possible position of a rectangular hut.

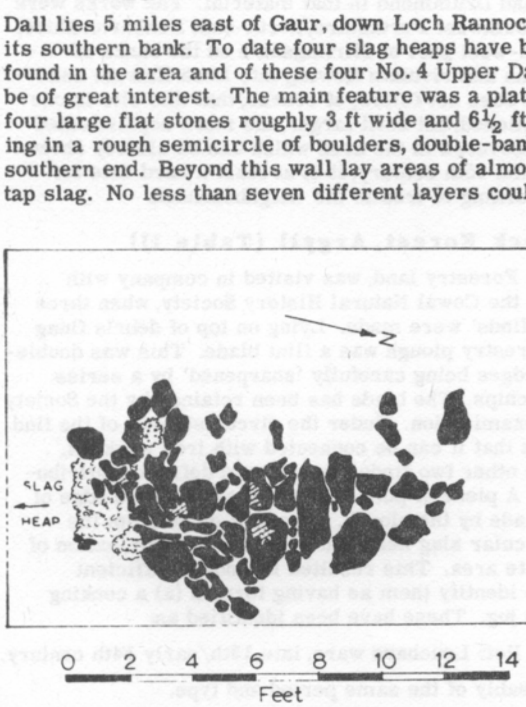

Fig. 3 — Smelting hearth at Upper Dall, Rannoch (site No. 4). This site was remarkable in that it had a large paved area. It also had a double layer of stones at the south end forming a low wall. Three distinct areas of adhesion could be seen on the paving. It could be that the top left circular area, with a large lump of slag, is the centre of the hearth. The large almost circular stone to the left of centre tips sharply downward to the base of the wall and contains the third area of adhesion

No. 5: Outer Dall

Unfortunately this site had been so cut about by the plough that no excavation could be attempted. Samples of slag were recovered.

No. 6: Lower Dall

This site, situated in a planting of some age, was difficult to examine. A 2 ft thick layer of sand covered the slag heap, which was of no great size. An area of tap slag was recovered in reasonable condition but, when this was followed back, an old tree was found to be growing on top of the position assumed to be that of the hearth. The nearest stream to the site is 50 yd away, and so it may be taken that the sand had been washed down from the hillside over a long period of time and before the area had been covered with trees.

No. 7: Leagag

A mile due south of Site No. 1, on the western ridge of a hill (Leagag, 1909 ft) another slag heap was found. It lies in a most difficult, if picturesque situation, situated as it is on a narrow ledge with a steep slope in front. Down this forward slope lies a large quantity of slag. Access is really only possible from behind the ledge on which the hearth stands—and that with difficulty. A very turbulent stream with a series of falls is 15 ft to the west of the site, which is located roughly on the 1450 ft contour. It is a very puzzling site on which to find a hearth.

Nos. 8 and 9: The Red Stable, Glen Comrie

Glen Comrie is a comparatively narrow valley leading west from Bridge of Gaur to the more open Moor of Rannoch. The high ground on the north side of the valley is dominated by the hill of Meall Chomraidth (1522 ft), whilst the southern side is a line of hills rising to over 2000 ft. The valley floor is flat, marshy, and drained by the Chomraidth Burn flowing east into Loch Rannoch. Three miles up this valley from the Loch, and on the lower slopes of the hill, there is a succession of natural platforms or small plateaux. One slag heap was discovered on one of these on the 1000 ft contour. The heap was circular, roughly 15 ft in diameter. The hearth is still to be found.

The second slag heap was located within a planting, about 300 yd to the north and almost on the valley floor. The site had been too badly damaged to expect any results from excavation. No. 24, Darachan, the latest one to be excavated, lies directly north across the valley on the 1000 ft contour and is fully reported upon later in this report.

No. 10: Station Road, Rannoch

This site, on private ground, lies on the top of a moraine mound on the right-hand side of the road leading to Rannoch Station. It has not been disturbed as far as can be seen. The slag heap is fairly large and has spilled down over the west and north sides of the moraine.

No. 11: The Greens, Moor of Rannoch

The Forestry road running west through Glen Comrie ends about 5½ miles out into the Moor. About 400 yd still further west and beside a large stream a 'box' type bowl hearth was uncovered. It is similar to No. 1 with a protrusion of slag about 7 in high at the southern end. The plough had just missed the bowl but had scattered a number of large stones, one or two of which bore visible signs of having been in close proximity to heat. An interesting point regarding this hearth was the fact that the interior had been deliberately filled with a number of thin small stones set on end. I first examined this site in 1965 and then left it to be excavated the following year. However, I was not able to return until this year (1970), only to discover that the young trees have grown so high as to lose for me all landmarks. A close search failed to refind it, but the Forestry Superintendent, Mr P. Garrow, has kindly indicated that as the occasion arises a fullscale search will be made.

Nos. 12, 13, 14, and 15: Comrie Hill, West Camghouran Farm, and Coille Bhienie

These are reported sites and at least one (Camghouran) will be excavated.

Nos. 16, 17, 18 and 19: Barracks

These were discovered while working on No. 3. All the heaps are large, and are within yards of each other. A stream had run close by the site, but when the Forestry road was constructed its course had to be diverted. The actual position is at the termination of a branch road which turns off northwards from the Glen Comrie Forestry road at a point 3 miles from Gaur.

No. 20: Aulich, North shore of Loch Rannoch

This site was reported to me by Mr Dickson of the Ordnance Survey Department. It is on the ground of Viscount Wimborne of Craiganour, about three-quarters of a mile from the Loch shore and on the 1000 ft contour. The situation is open and the slag heap can be easily distinguished by an almost circular mound covered with short green grass, in sharp contrast with the heather-covered ground around it. The mound measured approximately 27-28 ft in diameter and was 4 ft thick at the centre. It did not appear to have been disturbed. This point is important, since when the mound was opened by trenching a well laid structure of large stones was exposed, more than half of it under the slag of the mound. Of course, a great deal of this overlay could no doubt have been caused by slip from the upper part of the mound. In shape the structure is a broad arrow-head, the arms forming an angle of roughly 90°. The point of the 'arrow' is to the south and the longest arm (12 ft 6 in) points approximately NE. The other NW arm is much broken at the farthest point from the tip of the arrow and is only some 8 ft long. The width of both arms is a fairly constant 3 ft. There is only one layer of stones forming each arm. Dr Tylecote suggests that the structure is probably the foundation of some form of shelter, and indeed if it were higher it would certainly give protection against the prevailing wet SW wind. The site is very exposed on a bare hillside and I should have welcomed some form of shelter several times when I was there. With regard to the fact that so much of the structure lay under slag, my latest experience on No. 24, Darachan (see below) would indicate the amount of movement of slag from the higher part of the mound to around the edges is quite considerable. Although a quarter of the heap was removed, i.e. the quarter covering the stones, no trace of the hearth was found, but there are three-quarters of the mound left to examine. The site was covered in but will be re-examined later. If the ore used was bog iron, it is likely that two large depressions in the hillside quite close by, now filled with water, could be the places where the bog iron was obtained. Mr Wilson, the farmer, indicated that once, under conditions of severe drought, the bottom and sides were seen to be covered with a reddish-brown deposit, left when the water had evaporated.

No. 21: Balimore, Balquidder

Examination of this site showed that a part of the farmstead had been built on top of the area. The slag heap apparently had been where the garden now is, and the occupiers over the years had continually turned up slag when digging the ground.

No. 22: Loch Voil, Balquidder

This site was reported to me by Mr Dickson of the Ordnance Survey Department. It is on the banks of a stream close to the Lochside. It is on private ground, and is still to be excavated.

No. 23: Stronachlachar, Loch Katrine

This was an interesting site, but a difficult one to examine. It is beside a large stream, 300 yd north-west of the house occupied by the manager of the Glasgow Corporation Waterworks. A few yards away are the ruins of a very old cottage which is enclosed by a very old turf dyke. From this dyke the remains of 'lazy beds' can be traced, running downhill. There was apparently no slag heap but pieces of this material seemed to be scattered over a wide area, although in no great quantity. On examining the foundations of both the cottage and the dyke, I found that slag had been used as 'bottoming' for both. Close search discovered the hearth. Although it had been badly damaged it still retained a half sphere of slag within the bowl. This had been scooped out of fine sand and, where it could be measured undamaged, was 17 in in diameter. The half sphere of slag measured 7½ in across the undamaged diameter and 5 in from the circumference to the broken centre. Some large stones were found around the edge of the bowl.

An interesting point arises regarding a site such as this in the Loch Katrine area. G. Turner in an article printed in Volume 1, 1907 of Scotia, the journal of the St. Andrew's Society, indicates that in 1456 the Laird of Buchanan obtained the licence to manufacture iron and to pay the Crown rent of Duchray and Drummond in that material. The works were situated in southwest Perthshire, north-east Dunbartonshire, and the north-west part of Stirlingshire on the banks of small streams and rivulets flowing into Loch Katrine and the Forth. It does not follow, of course, that this site is one of these mentioned, but until larger and more sophisticated sites are discovered in the area which can be clearly shown to belong to the 15th century, it is at least a hard date for basing the working of iron in the neighbourhood.

Ardmarnock Forest, Argyll (Table II)

This site, on Forestry land, was visited in company with members of the Cowal Natural History Society, when three interesting 'finds' were made. Lying on top of debris flung up by the Forestry plough was a flint blade. This was double-edged, both edges being carefully 'sharpened' by a series of pressure chips. The blade has been retained by the Society for further examination. Under the circumstances of the find I do not think that it can be connected with iron workers. However, the other two finds can be more definitely attributed to them. A piece of pottery protruding from the edge of the trench made by the plough, and a foot or so from the spill of a circular slag heap, led to a careful examination of the immediate area. This resulted in finding sufficient fragments to identify them as having formed (a) a cooking pot, and (b) a jug. These have been identified as:

(a) Cooking Pot: Leuchars ware, late 13th/early 14th century.

(b) Jug, probably of the same period and type.

The Cowal Society undertook further excavation of the site but to date have not found the hearth (1970).

Cairndhu, Cairnbaan, Crinan, Argyll (Table II)

This site is on Forestry ground and was reported to me by Mr G. Davis, Forestry Estate Officer. It is situated on the southern flank of high ground above the Forestry Offices and overlooking the Crinan Canal. It had been the object of previous curiosity and some slag lay scattered over the mound which was small and circular.

TABLE II List of slag heaps and furnaces

Based on personal observation or from information supplied by the Forestry Commission and other sources. They are additional to those shown and numbered on the site maps and described in the text.

Slap Heaps	Area	County	National Grid Ref.	Remarks
1	Top of West Lomond	Fife	NO 197068	Under the Mountain Indicator
1	Blackmount Estate	N. Argyle	NM 670590	
13	Sunart Forest and on Loch Sunart side	N. Argyle		No detailed reference
1	Carradale, Kintyre	Argyle		100 yd from Pier
1	Glendaruel Forest, Loch Ridden	Argyle		
1	Above Glendaruel Hotel	Argyle		
1	Cairndhu, Crinan	Argyle	NR 828903	Examined: circular heap: hill site.
1	Isle of Jura	Argyle	NR 604804	Checked
1	Otter Forest	Argyle	NR 946797	Checked
1	Otter Forest	Argyle	NR 946799	Checked
1	Otter Forest	Argyle	NR 947798	Checked
1	Otter Forest	Argyle	NR 950797	Checked
1	Lindsay Farm, Otter Ferry	Argyle	NR 961808	Checked
1	Ardmarnock Forest, nr. Kames	Argyle		Pottery sherds found
20	Lochgoilhead area (four heaps checked)	Argyle	NN 218018 NN 174001 NN 177004 NN 193054	
1	Glengarry Forest	Inverness	NH 205005	
1	Naver Forest, above Rossal Township	Sutherland		
1	Carradale, 100 yd from Pier	Argyll		
20	North shore of Loch Maree Col. Whitbread Estate	N. W. Ross-shire		
25	Glendochart Forest (Strome section)	Perthshire	NN 378238	One heap checked
1	Glendaruel Forest, Loch Ridden	Argyll	NS 016822	
1	Above Glendarual Hotel	Argyll		
20	Lochgoilhead (four sites checked)	Argyll	NN 218018 NN 174001 NN 177004 NN 193054	Site checked Site checked Site checked Site checked
1	Loch Lomond, N. of Luss	Dunbarton	NN 348968	Site checked
1	Loch Lomond	Dunbarton	NS 355945	
1	Head of Loch Ridden	Argyll	NS 016822	

No. 24: Grundd nan Darachan, Rannoch (Table 1, Fig. 4)

The name is that of an old ruin about 200 yd west of this site, which is on a flat-topped knoll 40 yd off the Barracks Forestry road on the left going west. This is the first site of all those examined in the Rannoch area which is easily accessible and allowed a complete and careful archaeological search. The slag mound had been circular, but slip to the west down a slight slope gave it now a rather pear shape, the 'bulb' being on the higher side. I marked off an area 20 ft by 20 ft which included a large part of the slag heap. When the turf and heather were removed, followed by a 6 in layer of soil, several large stones appeared. One was quite flat-topped with a slightly sunken area about 18 in by 12 in which seemed to have an artificial appearance of chip marks or peckings. Lying beside this boulder was a large granite pebble which had one flat face. It fitted the hand perfectly with the flat face downwards. Without proof it cannot be stated that this was used as a rough and ready anvil, but it is at least possible. As the various layers of soil were removed the original surface became obvious, with the various gradations of colour from brown through red-brown to the usual charcoal black. When the slag heap was skinned of turf, it was obvious that the overspill was between 3 and 4 ft all round. Work was now concentrated on moving the slag from the east or slightly higher side on a segment of the circumference measuring 18 ft. The first hearth was found about 3 ft within the slip of slag from the mound. It is a bowl type, with a quantity of slag adherence standing up about 8 to 9 in above the level of the base bowl. This projection of slag was on the north west side of the bowl and nearest to the heap. Almost a half sphere of slag remained within the bowl.

Moving north and following the curve of the slag heap, a second hearth was uncovered. The median line drawn between the usual two stones on the east side, and through the centre of the bowl ran due east to west, the western end be-

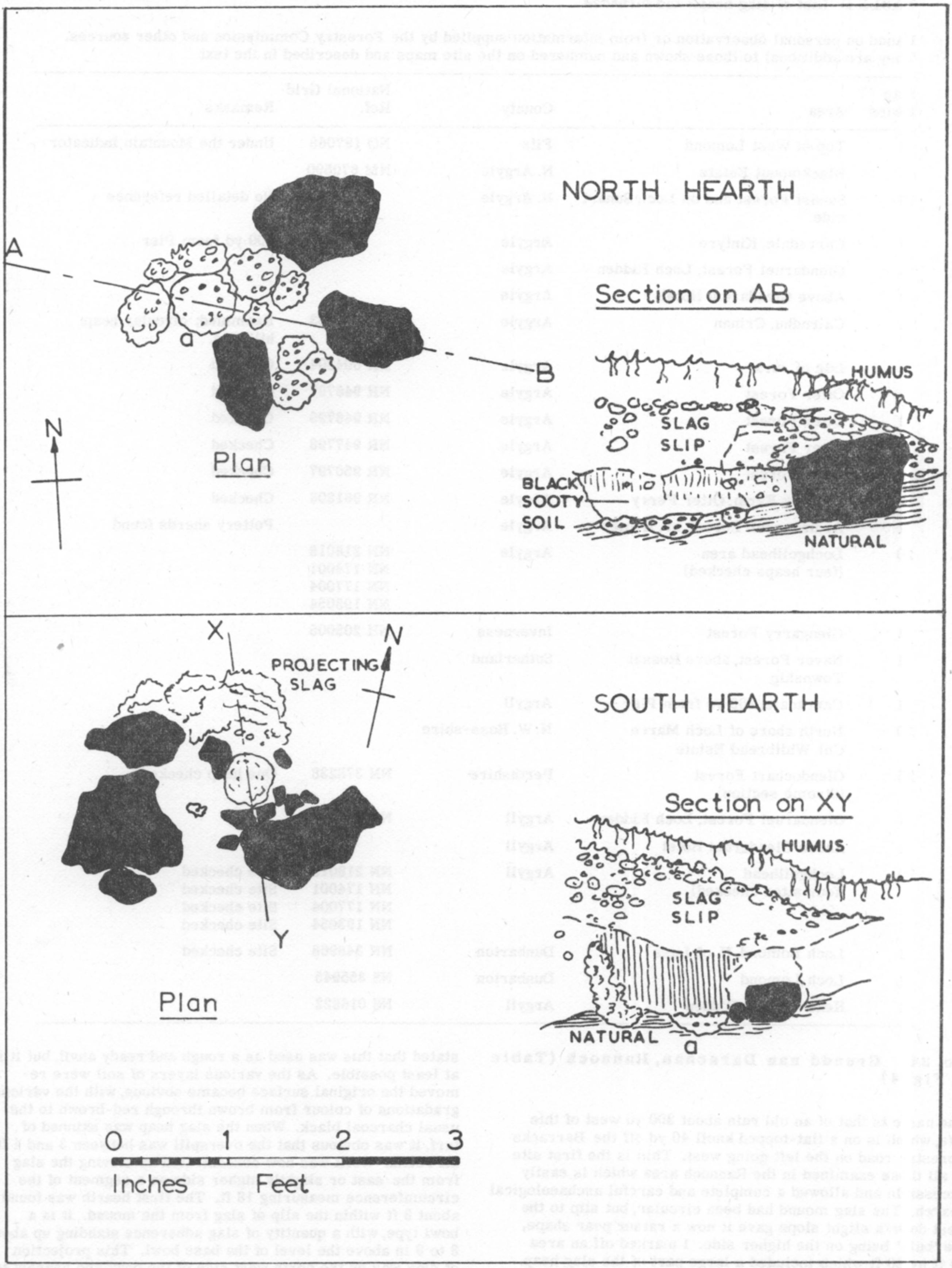

Fig. 4 – Smelting hearths at Grundd nan Darachan, Rannoch. Site No. 24. The two hearths were 7 ft apart on the east and higher side of the slag heap. The letter "a" indicates the position of the hearth bases.

ing nearest to the slag heap. Whereas the first hearth retained its bowl-like character, this second hearth was different in all respects but one. Beginning with two moderate sized stones at the west end, a space, quite flat, was lined or paved with lumps of heavy rust-coloured slag. This formed a flat surface about 10 in by 10 in. This was immediately followed by what appeared to be a flat circular piece of slag 5½ in in diameter. When this was removed it proved to be a 'half sphere', 3 in thick at the centre point, and was obviously the bottom of a bowl hearth. Another lump of slag of 6 in by 5 in completed the hearth. There were no stones enclosing this end. The thickness of the filling (of reduced charcoal and earth) was on average 6 in thick, while the top covering of slag which had slipped over all varied from 8 in at the eastern to 18 in at the west end.

This is the first time I have come across more than one hearth associated with a slag heap in this area, but since most of the slag heap sites are in very difficult ground, it is possible that some of the others might still contain a second or even a third hearth. For example, the very large slag heap at the No. 2 (Dunans) site which is about four times the size of this one at Darachan, is very likely to have had more than one hearth. My experience on the latter site would lead me to suggest that close attention (where the condition of the site allows) whould be paid to the slag slip around the perimeter of the heap.

THE FINDS

Appearance of the slag

The appearance of the slag varies in the heap from small to fairly large rough cindery masses, sometimes containing small particles of charcoal. Closer to the hearths themselves, the slag has the usual appearance of having had a toffee-like consistency, with the top surface showing the ripples of flow. Within the bowls the slag takes on a rough craggy appearance, and there would seem to be a rustiness in colour lacking in the slag discharged on to the heap.

A few fragments of heavy compressed sandy material found in association with some of the other sites were found lying on the original surface. This must be poor-grade bog iron. No iron nodules were detected.

The fuel

Random samples of charcoal found on the various sites were identified as:

Scots Pine	in a ratio of 4 to
Ash (not mountain ash)	3 to
Oak	1 to
Birch	1

I am informed that in the Rannoch area ash and oak are now uncommon, especially on the Moor.

Observations on the hearths

Where it was possible to recover the actual hearth, the type pattern was as follows:

Circular 'bowl'	No. 23: Stronachlachar, Loch Katrine No. 24: South hearth, Darachan No. 4: Upper Dall (probable)
Rectangular	No. 1: Bridge of Gaur No. 24: North hearth, Darachan No. 11: Outer Barracks
With stone-flagged area	No. 4: Upper Dall No. 3: Barracks
Arrow-shaped construction partly under slag heap	No. 20: Aulich
Clay observed either in furnace (i.e. as 'bedding' or in close proximity to it)	No. 1: Bridge of Gaur No. 8: Glen Chomrie No. 4: Upper Dall No. 6: Lower Dall Ardmarnock
Streams in vicinity (i.e. not further away than 40 yd)	In every case with the exception of Nos. 10 and 20, and Cairndhu. There had been a stream very close to the Barracks groups of five (Nos. 3, 16, 17, 18 and 19) but a new Forestry road has diverted it into a new bed.

Slag heaps

There are two types of slag heap, those I would describe as of the 'crag and tail' type and those which are circular. The hearth associated with the first type is usually found at the 'crag' end, while the hearths associated with the circular type can be anywhere on the perimeter of the mound. The largest 'crag' type was No. 2. (The Dunans), 35 ft long by 22 ft wide. It also contained the greatest amount of charcoal dust and debris.

The circular mounds were at No. 20 (Aulich), No. 8 (Glen Comrie), No. 24 (Darachan, Cairndhu), No. 14 (West Camghouran), and No. 22(Loch Voil). Many of the others must have been circular also, but had been so badly damaged by the ploughs that actual identification was difficult.

At No. 7 (Leagag) the slag had been tipped down the steep hill slope, and at No. 4 (Upper Dall) the slag, apart from the flat area of tap slag, had been allowed to fall into a small valley. At Stronachlachar the slag heap had been dispersed. This had happened also at No. 1 (Gaur). It was impossible to be quite sure about the shapes of Nos. 3, 16, 17, 18 and 19 as, again, the ploughs had torn up the whole area.

The direction of the hearth openings

I found that there was no settled direction in which entrances pointed (to receive the draught, as it were). If I take the usual two stones which seem to point to the position of the tuyere as being the opening into the hearth, the 'table of direction' reads as follows:

SW.	2	S.	3	SE.	1
W.	3	NW.	1	E.	1
N.	3			NE.	1

The prevailing wind in the area is from the south-west, and therefore, if natural draught had been the method used to increase the temperature within the furnace, one would have expected the hearth entrances to open to the south-west.

Macadam[1] in his article on the subject, put forward the theory that sites on hill tops and in narrow valleys had used natural draught to assist in raising the temperature within the burning mass of slag and charcoal. Modern investigation has proved that to obtain and sustain the necessary temperature to smelt the ore (a temperature of 1100-1200°C is required) forced draught from a pair of bellows must be used. It is not necessary to place the hearth in such a way as to have the assistance of the prevailing wind. That only two hearths out of fifteen excavated had the 'entrance' opening to the south-west would seem to argue that the ironworkers had no need to depend on the natural wind.

If further proof were required, the experiment of Professor M. J. O'Kelly[2] of Cork, in constructing a bowl furnace based on the finds of H. E. Balch[3] at Chelms Combe, Somerset, and Lady (Aileen) Fox[4] at Round Pound, Kestor, Devon, in which he succeeded in producing iron and slag comparable to that found on ancient sites by the use of double bellows, would seem to be conclusive. It is interesting to compare the bowl-type furnace found by Lady Fox[4] at Kestor (Fig. 5) with those I found at Gaur and Darachan (Nos. 1 and 24)

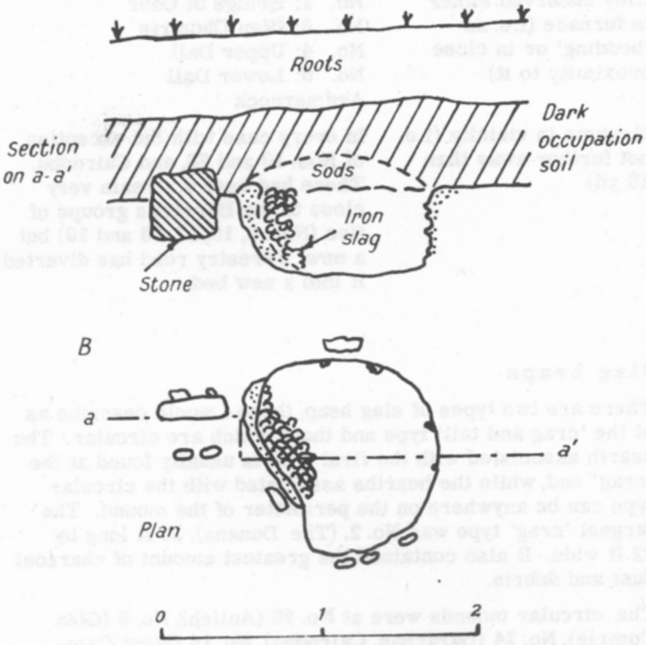

Fig. 5 — Plan and section of the iron-smelting hearth found at Round Pound, Kestor. (Reproduced by kind permission of Lady Fox and the Devonshire Association for the Advancement of Science)

OTHER SITES

The Cowal Archaeological Society were good enough to give me details of other bloomeries in their area. Mr MacIntyre visited most of the sites and supplied many of the details noted belwo.

Above Caladh Farm. (noted as Upper Caladh on the 6 in OS map).

Strathlachlan	NS 032972	
	NS 034969	Both on the moor west of Sunfield
Strachur	NN 092030	100 yd above the electricity line.
	NS 132965	
		Also one near the fourteenth milestone to Dunoon.
Glendarual	NS 003850	Ardachearanbeg Farm.
Dunoon	NS 163791	Slag mound cut into by small burn immediately west of the Cashel wall.
	NS 166779	Mound above and 500 yd west of Dunloskin Farm.
	NS 166787	Mound on edge of tree line about 200 yd south of Chapel Burn.
Toward	NS105700	Slag heap behind Knock Dow House. Information can be got at Achafour Farm.

Two more have been reported, one above the junction of Whistlefield Road and Loch Eck Road, and another at Achnabreck above the small telephone exchange.

Macadam[1] mentions by district name but not by any map reference a number of sites where slag heaps were to be found. It does not seem from his writings that he ever excavated one, but his list is of interest (it is noteworthy that not one of the sites he mentions in Perthshire coincide with my own):

No. of slag heaps	County	
2	Aberdeenshire	
17 plus	Argyll	Mentions several in a given area
3	Banff	
12	Buteshire	
1	Tarbet, L. Lomond	
	Dumfriesshire	No number given several reported
12	Elgin	
15	Inverness-shire	
5	Nairn	
12	Perthshire	
1	Stirlingshire	Rowardennan, L. Lomond
14	Ross-shire	
7	Sutherlandshire	

CONCLUSION

The limits of the wild and desolate area known as the Moor of Rannoch are difficult to define, but might fairly be said to enclose an area bounded by Mamore Forest to the north, Glencoe to the west, Strathfillan to the south, and Loch Rannoch to the east. The surface is varied, with streams and even rivers draining it, mountains enclosing it, and lochans, moraine mounds, and peat bogs spreading over the flatter stretches. The most striking feature, one which draws attention to itself, is the immense quantity of glacial drift boulders, nearly all granite, which lie in disordered masses almost everywhere the eye can reach. These rocks can reach the dimensions of a small cottage, and there are many perched on top of each other, tribute to the slow-melting ice which brought them to their resting place. Moss grass, heath, heather, and stunted bushes clothe the ground. Up to about ten years ago trees were few, but the work of the Forestry Commission is rapidly changing the face of the Moor. In twenty years' time the Moor of Rannoch will again appear to the onlooker much as it must have done to the iron workers at their hearths. The proof that trees once grew abundantly lies just under the present surface. The Forestry ploughs tear up and expose the roots and stumps of earlier forests, the raison d'être of the iron industry in the area. The large proportion of pine charcoal in the slag heaps is supported by the fact that the majority of these roots are of pine trees. That the Moor was not always the desolate and deserted place it is now is proved by the ruins of ancient clachans which are to be found in many secluded and lonely spots in the heart of this amazing place. I am quite certain that there are many more bloomeries to be uncovered in Rannoch, and that in the 15th century at least the area was a 'good going concern'.

APPENDIX

Notes on the composition of the slags and ore

Mr Archbald MacIntyre of Lindsaig Farm, Kilfinan, Argyll, was responsible for the discovery of several sites near Otter Ferry, Loch Fyne. The material gathered from these is of some interest, and the following notes were made on them by Dr R. F. Tylecote:

Otter Forest, Argyll	NR 950797—Ore: Iron hydrate. This specimen lost 21.6% of its weight upon ignition. Its black colour shows that it has a high manganese content.
Otter Forest, Argyll	NR 947798—Sandy bog ore; low grade. Tap slag
Otter Forest, Argyll	NR 946799—Heavy iron tap slag.
Otter Forest, Argyll	NR 946797—Heavy iron tap slag.
Lindsaig Farm, Kilfinan	NR 961808—Heavy iron tap slag.
Cairndhu, Crinan, Argyll	NR 828903—Heavy iron ore, possibly bog iron.
Otter Forest (Strone section)	NR 948796—Brown bog ore. Tap slag.
Kilfinan	NR 931723—Sandy black bog ore.

Mr MacIntyre kindly took me over the ground mentioned above in the Kilfinan area. Much of this had been ploughed for tree planting and very large deposits of the rich black ore were easily noticed. A very pertinent question arises: but for the tearing up of the ground by the modern ploughs, it would be almost impossible to find the spots where the ore is lying. It is at a depth of 10-15 in beneath the present surface and in pockets of 2-3 ft in width and up to 10 ft in length. There are no indications on the surface which might show what lies beneath. The thought which at once springs to mind is, how did the ancient smelters know it was there, and in sufficient quantity to justify a small industry?

Time permitted only the examination in any detail of one of the slag heaps in this area, but a hearth was found with the now usual projecting slag adherence to the bowl. This one was of interest as it had a thick lining of red clay within the bowl.

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2. M. J. O'Kelly: Bericht ü. den V. Internationalen Kongress für Vor- und Frühgeschichte, Hamburg, 1958.
3. H. E. Balch: 'Mendip Cheddar; Its Gorges and Caves', 2nd Ed., 1947 (See also excavation report in Somerset Arch. Nat. His. Soc. Trans., 1925.)
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ACKNOWLEDGEMENTS

Over the period which this investigation covers I have been indebted to many people who have assisted me in a multitude of ways. I should like them to know that I appreciate and value that assistance.

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I am especially grateful to the following: Miss Alison Cameron of Bridge of Gaur whose 'find' started this whole investigation; Mr and Mrs D. Cameron of Bridge of Gaur for their help and great kindness; Mr S. Seal, Sileby, Lancs., for the analysis of material; Mr E. Talbot, Archaeological Dept., Glasgow University, for the dating of the Ardmarnock pottery; Lady Fox and the Devonshire Association for the Advancement of Science for permission to use the plan and section of the bowl furnace found at the Round Pound, Kestor; Miss Ailleen Orr and Miss Morag Carruthers of Stronachlachar; Mr J. K. Dunn, McLaren High School, Callander—the Loch Katrine sites would not have been brought to my notice without their help. Active and most useful assistance was given to me by Mr Don Lindsay of the Forestry Commission, to whom I am most grateful: I could not have had a better assistant and without him many of the sites would not have been discovered.

Finally, I wish to express my thanks to the many others who gave me information regarding the location of the sites.

The charcoal finery and chafery forge

G. R. MORTON AND JOYCE WINGROVE

In 1963, Morton[1] examined the technical aspects of the charcoal finery and chafery forge, and for historical considerations he used the accounts given by Pashley,[2] Percy,[3] Bauerman,[4] and Fell.[5] The work was based on the process operated in the Lake District in the 18th century.[5] In 1964 the same author[6] examined the process used on Cannock Chase (South Staffordshire); on that occasion the work was based on the Anglesey Papers in the William Salt Library[7] and the account given by Plot.[8] The recent excavations by Davies-Shiel[9] and the work on slags being conducted at the Polytechnic, Wolverhampton, bring new light to the process and the necessity for a reappraisal.

With the introduction of the charcoal blast furnace to the Sussex Weald in c. 1490, the Midlands in 1561, and the Lake District in 1711, a method for the conversion of the pig iron produced in the blast furnace into the form of malleable bar became necessary. In the old bloomery process for producing bar direct from the ore the output was very low (in the order of 1 to 2 cwt of bar iron per furnace per day), whereas the blast furnace could produce 2 to 2½ tons of pig iron per day. In order to convert this pig iron into malleable bar, the impurities were first removed by oxidation in the finery hearth and this stage was followed by reheating in the chafery fire and by hammering into bar.

The layout of a typical finery forge based on the painting by Peer Hillestrom[10] is given in Fig. 1, and a reconstruction of a 17th century finery as given in Appendix XV of Schubert's book[2] is reproduced in Fig. 2. These can be compared with the furnace found during the excavation of Stony Hazel by Davies-Shiel (Fig. 3). In addition to the general layout, the painting gives much detail. The details reconstructed in Fig. 2 are in complete agreement with those of the excavation in Fig. 3. In the finery (on the right-hand side of the centre of Fig. 1) a pig of iron is to be seen, one end resting in the fire with the other in the pig hole. Both pig and pig hole appear much larger than the actual size, but nevertheless the position of the hole agrees with that shown in Fig. 2 and that found on excavation in Fig. 3. In the painting an iron pillar probably supported the roof, whereas Figs. 2 and 3 show the support to be of stone construction. It will also be seen that a shield is provided to protect the operator from the glare of the fire. Schubert cites this as either mortar or hard wood resting on a bar called a 'morris' bar.[11] The accounts of Cannock forge include the item:

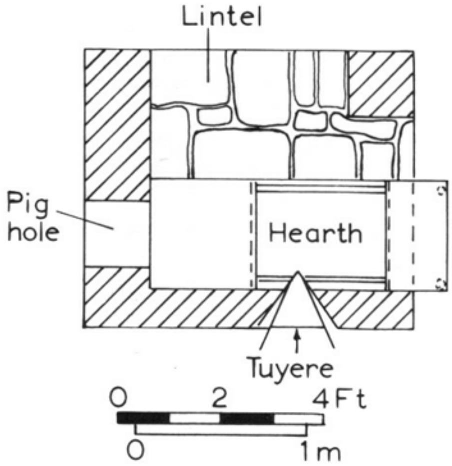

Fig. 2 — Reconstruction of a 17th century finery (after Schubert[2])

Fig. 1 — The interior of a Walloon forge at Forsmark, 1793 (after Hillestrom)

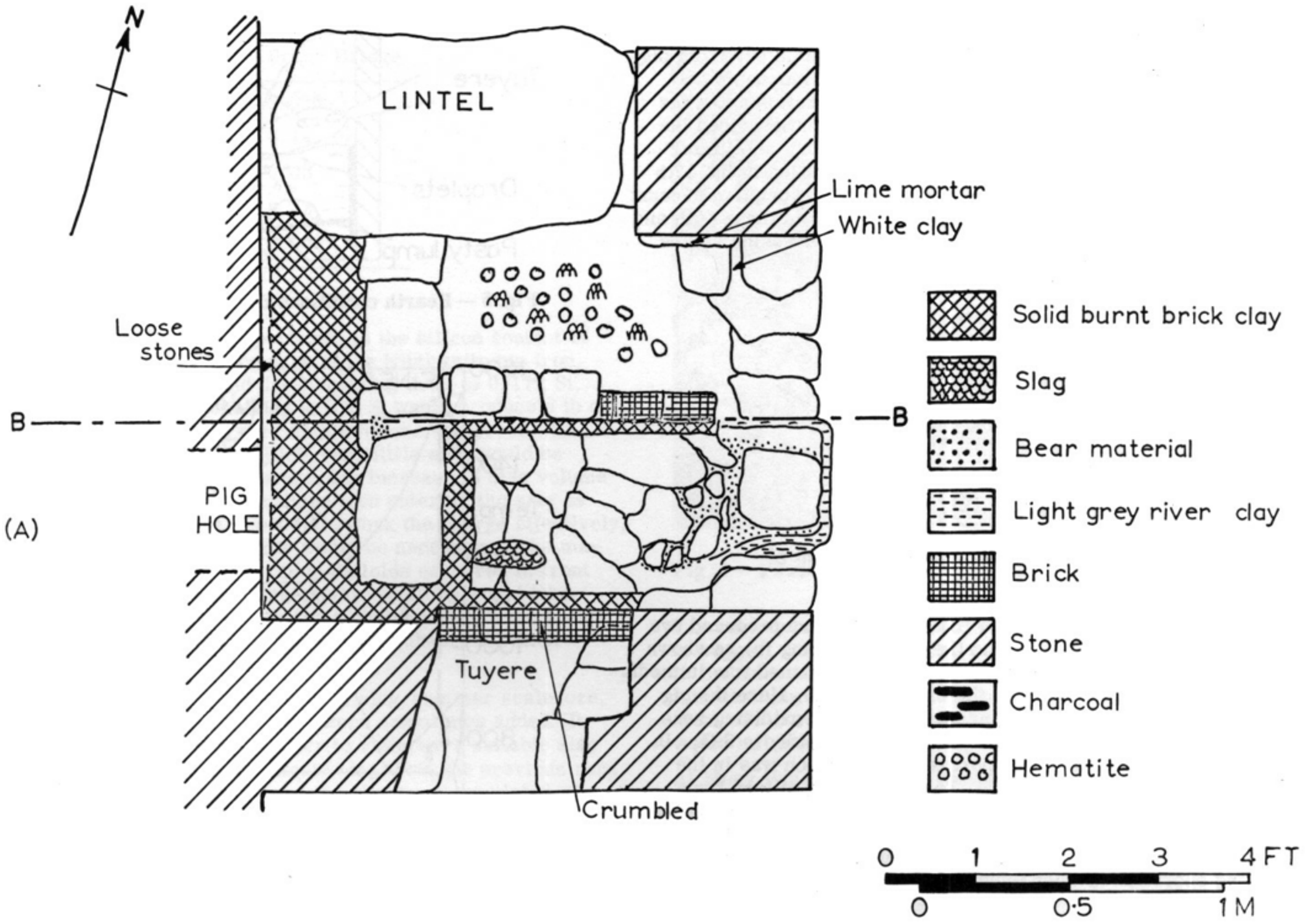

Fig. 3 — The finery at Stony Hazel

Finer	To John Mathews for fynyng the said iron	47s	4d
	to hym for mendyng his morris		7d

This confirms the use of the eyeshield in this country.

Pashley[2] describes the construction of the hearth proper and gives details of the iron plates which lined the well (Fig. 2). Prior to the commencement of the day's work, these plates were well brasqued with powdered charcoal which acted as refractory protection to the iron plates.

The chafery was essentially a reheating furnace and appears in Hillestrom's painting as a very much larger fire than that in the finery. This was due to the mode of construction, an excellent account of which is given by Fell.[5] In order to obtain a temperature suitable for forging, a muffle construction was necessary. The temperature attained in the furnace can be estimated from the appearance of the heated metal being transferred to the hammer in Hillestrom's picture. The release of masses of sparks from the hot end suggest a welding heat in the region of 1450°C. This degree of heat would be necessary to forge and weld the iron into a compact mass. According to Fell, the muffle was built in the form of a hollow beehive-shaped arrangement made from the waste material (ash, charcoal, small pieces of slag, etc.) left over in the furnace from the previous day's operation, and probably mixed with a binder such as clay. The foreplate of the chafery was in the form of a cast-iron plate, along which the blooms were skidded in and out of the fire. A simple saucer-shaped hearth sufficed the needs of the bottom, and as the slag formed it overflowed the hearth and ran through a gap between the foreplate and the hearth, and on to a sand floor where it collected in the form of the 'mossers' referred to by Fell.[5] No chafery has been found in the building excavated at Stony Hazel; it is however possible that one might exist in the building not yet cleared.

THE PROCESS

Pig Iron

Three general types of pig iron—tough, cold-short and blend metal—depending on the phosphorus content of the ore used, were produced in the charcoal blast furnaces. The analyses of tough and cold-short pig irons are given in Table I, from which it will be seen that the essential difference between them was the high phosphorus content (1.01) of the cold-short iron. This made it difficult to work in the finery and, as the name suggests, the resultant iron was cold-short. Both tough iron and blend metal were extensively used.

TABLE I Analyses of charcoal pig iron, %

	Tough		Cold-short
	Nibthwaite	Duddon	Little Aston
C	3.86	4.30	3.37
Si	0.85	0.65	0.28
Mn	0.05	0.10	0.91
S	0.11	0.124	0.081
P	0.029	0.023	1.01

Because of the low temperature at which the charcoal blast furnace worked, the pig irons produced were characterized by low silicon content. Where the phosphorus content was low, these irons were sufficiently tough in the cast condition to permit their use for such items as hammers and anvils, hence the name 'tough' pig iron.

Refining and fining

Percy[3] considered the production of malleable bar from pig iron in considerable detail, with particular emphasis on technical aspects and the processes in operation about the middle of the 19th century. Bauerman[4] also described the processes and introduced the terms 'refining' and 'fining'. Of the earlier processes, i.e. those in operation in the 17th and 18th centuries, Schubert gives a good descriptive account but does not consider technical detail. It is to these 17th and 18th century processes that the present discussion refers.

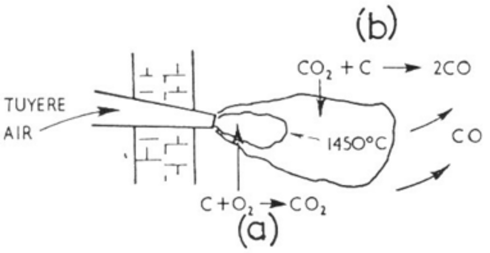

Fig. 4 — Combustion of charcoal in front of the tuyere

The burning of charcoal in front of the tuyere produced two zones, one oxidizing (a) and the other reducing (b), as shown in Fig. 4, and the maximum temperature attained was immediately in front of and above the oxidizing zone. Here the pig iron would melt readily and on entering the oxidizing zone the silicon of the pig iron would oxidize rapidly to SiO_2. In tough pig iron the major portion of the carbon was in the form of graphite (Table II). The removal of silicon from solution in the iron permitted some of the carbon to replace it as iron carbide (Fe_3C) and the remainder would be oxidized and pass up through the charcoal bed as CO. This desiliconizing operation is what Bauerman termed 'refining'.

TABLE II Analyses of pig and 'refined' iron, %

		Nibthwaite pig	Refined iron[13]
C	graphitic	2. 43	0. 01
C	combined	1. 43	2. 93
Si		0. 85	0. 173
Mn		0. 05	0. 05
S		0. 029	0. 037
P		0. 11	0. 16

When considering the reactions occurring during the refining process, Bauerman states 'The carbon, if it existed originally as graphite, first passes into the combined state, and is then converted into carbonic acid (CO_2) either by the oxygen of the blast, directly, or indirectly by the action of protoxide (FeO), peroxide (Fe_2O_3), or magnetic oxide of iron (Fe_3O_4) dissolved in the slag'. The effect of remelting Nibthwaite pig iron under oxidizing conditions can be seen in Table II, from which it will be noted that most of the silicon has been removed and some of the graphitic carbon has passed into combination with the iron.

The finery process therefore consisted of two operations following each other in the same furnace, without any marked division. The operation of refining occurred in the first melt-down. The workman then raised the pasty lump into the oxidizing zone in front of the tuyere when other impurities such as Mn and combined carbon were oxidized and the metal was said to be fined (Fig. 5). Thus the overall process consisted of a refining and a fining operation during which malleable iron was produced. The temperature in the hearth was very much lower than that in front of the tuyere (Fig. 4) and the falling molten droplets solidified and coalesced into a pasty lump with liquid slag in the interstices and around the mass.

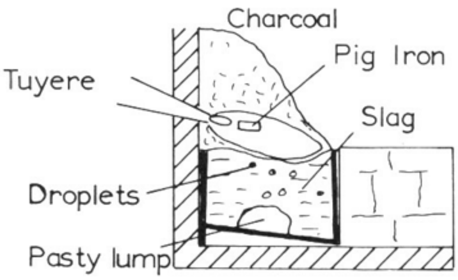

Fig. 5 — Hearth conditions during fining

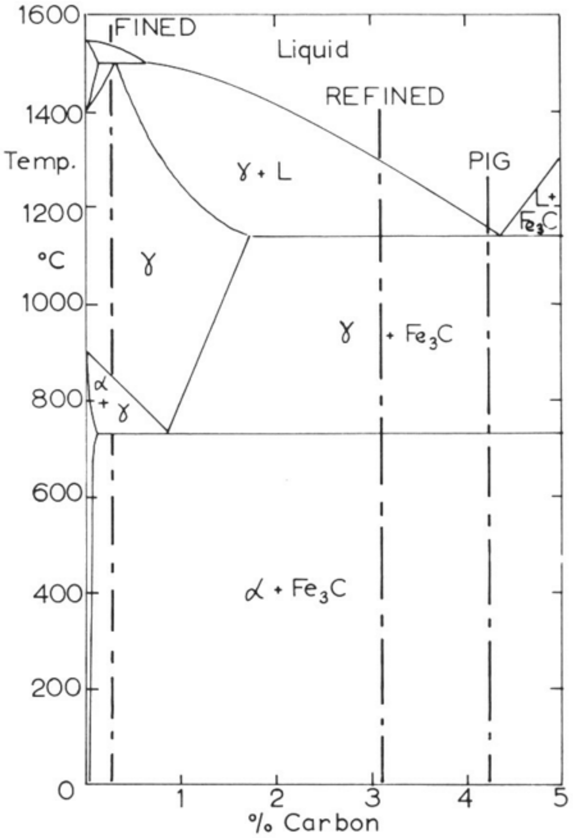

Fig. 6 — Carbon equivalents for stages of fining

The effects of refining and fining on the melting temperature of the pig iron can be seen in Fig. 6, where the carbon equivalent[14] of the iron, based on the formula:

$$\text{C. E. (wt\%)} = \text{Total carbon} + \frac{P}{2} + \frac{Si}{4}$$

is inserted into the iron-carbon equilibrium diagram for the various stages. Fined iron is very low in carbon and the increase in melting temperature from refining to fining can be seen in Fig. 6. During fining there would be a further gradual rise in the melting temperature of the iron, and at some stage during the operation the temperature in front of the tuyere would not be sufficiently high to keep the metal molten. Thus the finer was able to judge by the 'feel' of the metal when it was sufficiently fined, and any rabbling beyond that point would only result in excessive iron loss due to oxidation. The compositions of two typical fined irons are given in Table III.

Finery slag

The SiO_2 formed from the silicon in the metal would combine with some oxidized iron to form fayalite ($2FeO.SiO_2$) which, as slag, would descend in the molten form towards the hearth. The amount of slag formed during the refining op-

TABLE 3 Analyses of fined iron, %

	Nibthwaite	Penny Bridge
C	0.028	0.035
Si	0.23	0.14
Mn	0.13	0.09
S	0.024	0.12
P	0.31	0.209

eration was directly proportional to the silicon content of the pig iron. Thus in the case of the Nibthwaite pig iron, after initial melting and desiliconizing down to 0.17% Si, 100 lb of pig iron containing 0.85% Si would produce 5 lb of slag. This would be a very small volume compared with the metal volume. In addition, very little slag would be formed during the fining stage; any increase in slag volume would be mainly due to oxidized iron entering the slag as dissolved FeO. Thus in order to work the charge effectively, a much greater slag volume would be necessary. The majority of the oxidation of the metalloids occurred in front of the tuyere and some slag-metal reactions would take place in the hearth between the dissolved FeO in the liquid slag and the pasty metal. This would enhance the final decarburization of the metal.

In order to build up the volume of slag, hammer scale, ore, or even a little quartz or clay were sometimes added. It seems likely also that in order to maintain a suitable slag volume the main mass of liquid slag from the previous runs would be left in the furnace and only any accumulated excess over the workable level removed. Since the hearth was lined with charcoal-coated cast-iron plates which protected the furnace structure, little or no slag attack would occur, and so the slag composition was entirely dependent on the composition of the pig iron and the additives used by the finer. The constituents which would form on solidification would be similar to those found in Roman slags by Morton and Wingrove,[15] i.e. wüstite, fayalite, and a glass approximating to the composition of anorthite ($CaO.Al_2O_3.2SiO_2$).

Where hammer scale (virtually pure oxides of iron) was used to build up the slag volume, the resultant slags on fining would contain a high proportion of free wüstite, and set in a matrix of fayalite with only a small amount of glass. This is in agreement with slags found at Ipsley Forge (Worcs.) and Powick Forge (Worcs.), as shown in Table IV and Figs. 7 and 8. Percy mentions the addition of quartz or clay in the Franche-Comté process, but no direct evidence is available to suggest such usage in this country. The pig irons used in the finery were all cast from the charcoal blast furnace into sand pig beds and siliceous material would adhere to them. This siliceous material was slagged in the finery and would influence the final composition of the slag produced.

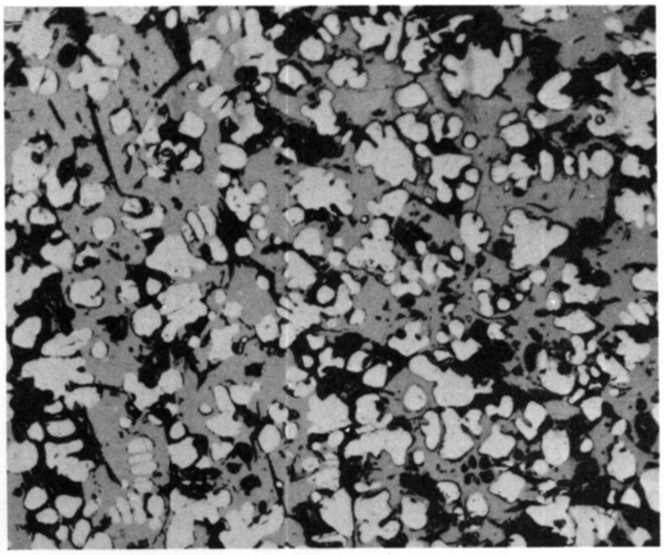

Fig. 8 — Powick forge slag (X 130)

At Stony Hazel an ore bin containing fine ore was uncovered on the site. Fine ore was also found embedded in the hammer-scale floor between the bin and the finery. In addition, ore was trapped in the slag, which is strong evidence of its use on that site. When ore was added, constituents such as FeO, SiO_2, CaO, MgO, MnO, Al_2O_3, P_2O_5, and S would affect the slag composition and volume. It is also possible that some of the Fe_2O_3 would be reduced as in the bloomery process, and the iron produced would coalesce with the pasty lump. The remainder of the Fe_2O_3 would dissolve in the molten slag where it would provide FeO for slag-metal reactions. The final slag would contain a large quantity of fayalite, glass, and wüstite in an amount dependent upon the degree of decarburization of the iron and the technique of the operator and his use of ore. The analyses and the calculated mineral phases of slags found at Stony Hazel, and New Weir (Forest of Dean) are given in Table IV, and the microstructures in Figs. 9 and 10. It will be seen that these structures agree

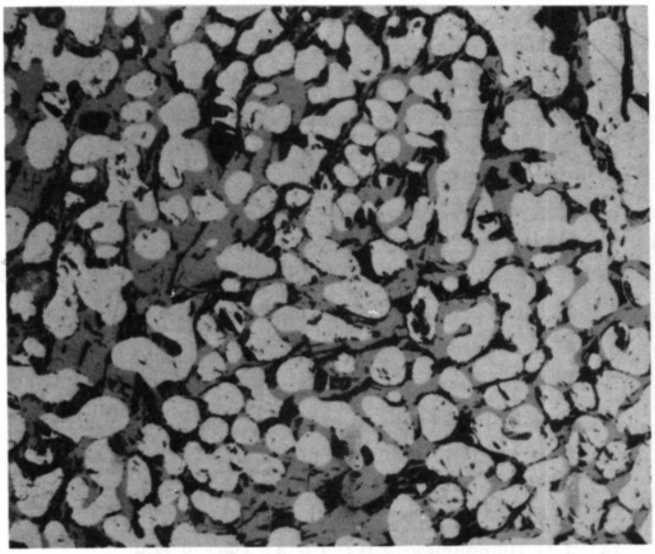

Fig. 7 — Ipsley forge slag (X 130)

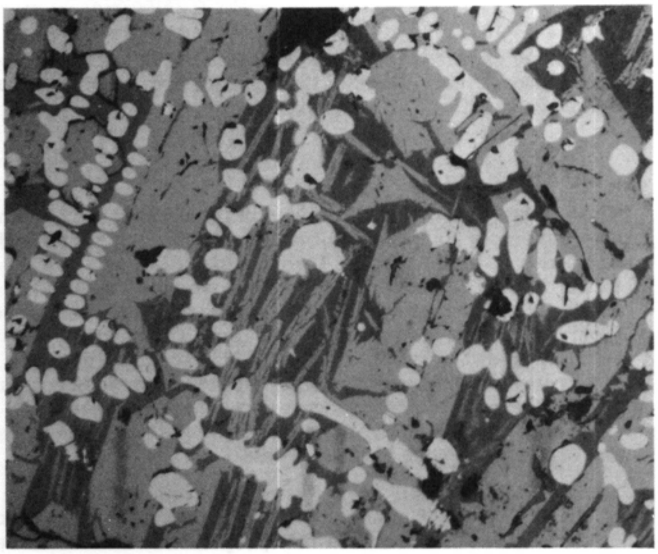

Fig. 9 — Stony Hazel slag (X 130)

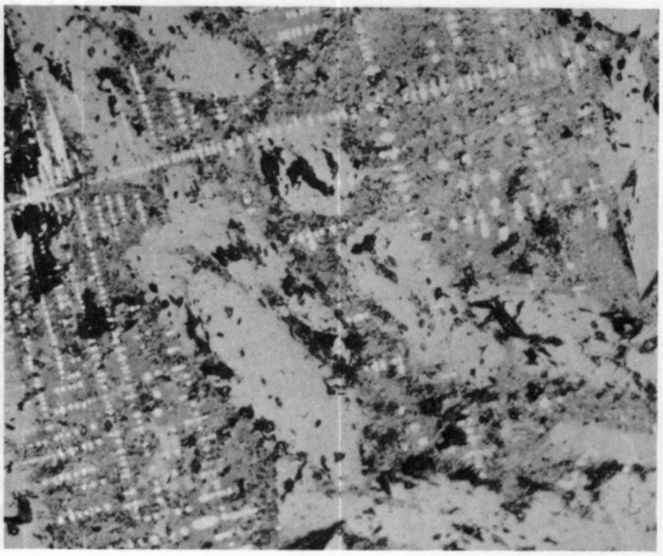

Fig. 10 — New Weir forge slag (X 130)

TABLE IV Analyses and calculated phases of finery slags, %

	Stony Hazel	New Weir	Powick	Ipsley
Fe_2O_3	3.20	2.57	9.10	11.20
FeO	56.90	58.31	65.10	69.10
SiO_2	24.20	26.40	11.20	7.70
CaO	2.50	2.40	3.10	2.50
MgO	0.90	0.84	0.29	0.10
MnO	0.13	1.41	3.83	0.58
Al_2O_3	8.90	6.20	3.50	5.70
P_2O_5	0.71	1.92	2.59	1.80
S	0.22	—	0.10	0.08
TiO_2	—	—	0.23	0.10
Fe	1.90	—	0.75	0.88
Wüstite	16.13		62.68	78.33
Fayalite	70.24		26.68	8.46
Anorthite (glass)	13.62		10.62	13.20

— = not determined.

with those expected from the discussion. Thus differentiation between finery slags of this type, Roman bloomery slags, and some medieval slags is extremely difficult.

Chafery slags

These slags are known in various districts under such names as mossers, in Furness and the Lake District, and gits and hambones in the Midlands. They are usually found in the form of large hambone-shaped lumps weighing up to about 56 lb and comprise two distinct layers. The slag was tapped from the furnace into a hole in the forge floor and, being poured somewhat 'wild' (i.e. gassy), the top layer consists of a frothy and porous mass whereas the lower half is more dense. Frequently many pieces of charcoal are found entrapped in the upper layer. The analyses of three mossers and one hambone are given in Table V.

Many variables could affect the composition and structure of chafery slags. The use of semi-refractory culm to make up the beehive muffle meant that proportions of it would be slagged during operation, and this could cause high SiO_2, CaO. and Al_2O_3 contents in the slag. In a similar manner the use of mineral fuel was first applied to the chafery long before any other type of furnace and, when used, ash from the fuel would automatically be slagged. Mineral phases such as hercynite, various silicates of lime, and magnetite might appear in addition to the usual wüstite-fayalite-glass complex. The former would would result from refractory contamination, and magnetite would be formed either from detached scale formed under oxidizing conditions becoming dissolved in the slag or from rapid cooling of 'wild' slag. At the present time chafery slags can best be identified by their visual appearance in the mass and the two-layered structure rather than by analysis and microstructure. It is hoped that further work will produce distinctive features that will assist positive metallurgical identification of these slags.

TABLE V Analyses of chafery slags, %

		Mossers			Hambone
	Nibthwaite	Sparke Forge	Penny Bridge Porous	Penny Bridge Dense	Ipsley Forge, Worcs.
Fe_2O_3	9.43	27.60	31.40	9.70	9.90
FeO	65.53	33.10	29.30	40.63	58.80
SiO_2	16.16	21.32	11.04	14.58	17.80
CaO	2.10	5.68	4.34	5.16	2.60
MgO	1.20	1.77	3.14	3.00	0.22
MnO	nd	nd	nd	nd	2.50
Al_2O_3	4.30	2.52	4.30	12.45	4.90
P_2O_5	0.23	0.12	0.05	0.05	2.01
S	0.47	nd	3.69	4.67	1.50
L.O.I.	6.20(gain)	6.50	12.90	3.95	(Fe 0.70)

nd = not determined

ACKNOWLEDGMENTS

The authors wish to thank Mr M. Davies-Shiel for supplying material and information regarding the Stony Hazel site and the Director of the Polytechnic, Wolverhampton, for permission to publish the paper.

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The examination of two samples of bloomery iron

G. T. BROWN

The following report concerns the examination of two samples of iron produced by the bloomery process. One of the samples was excavated from a post-Medieval site at Muncaster in Cumberland, and the other was produced by the operation of a modern reconstruction of a bloomery furnace. The reconstructed furnace was operated by Dr R. F. Tylecote of Newcastle University and used Northants ores. The post-Medieval sample was also supplied by Dr Tylecote who had been in charge of the excavations at Muncaster.

The bloomery process is essentially one of direct reduction of iron ore in which the ore and reducing agent (i.e. charcoal) are mixed and smelting is carried out in the solid state at a relatively low temperature. Whilst the essential reducing action takes place in the solid state, the slag which is formed by virtue of the silica content of the iron ore frequently becomes molten and is tapped from the bottom of the furnace.

The two pieces of iron examined did not appear to have received any hot working, the object of the exercise being to compare the output in terms of quality of the post-Medieval furnace with the modern reconstruction.

METALLOGRAPHIC EXAMINATION

A complete cross-section of each of the blooms was first prepared by cutting and grinding; this was then macro-etched to reveal the general structure and the nature of the porosity etc. Figures 1 and 2 show the macrosections. The darker-etching areas were higher in carbon content than the remainder; the very porous nature and remaining slag are features normal to bloomery samples. The Newcastle bloom (No. 6) appears to be slightly less porous than the post-Medieval sample.

Samples were cut from representative high- and low-carbon content areas in order to facilitate better polishing and examination of the microstructures.

In both cases the grain size was found to be exceedingly large. The higher carbon content areas showed a very coarse Widmanstätten ferrite and pearlite in both cases. In some places the carbon content was high enough to suppress ferrite formation entirely, and the structure was then of a very fine pearlite/bainite type. In neither of the sections examined did the carbon content appear to have risen far enough to result in free cementite appearing in the grain boundaries etc. Figures 3 and 4 show high- and low-carbon content areas of the Muncaster bloom and Figs. 5 and 6 show similar areas in the Newcastle equivalent piece.

If a general comparison may be made, it is that the Newcastle bloom had the appearance of a generally higher carbon content throughout. On a macroscopic scale the slag particles in the post-Medieval bloom had more of the grey/green fayalite constituent than did those of the Newcastle sample.

CHEMICAL ANALYSIS

The composition of the samples was determined by use of the Quantovac, small pieces having been separated from the blooms and remelted into a button under inert gas. Under normal conditions this technique retains most or all of the carbon content but this is clearly not true if any oxides are present, as is the case with the present samples. The remelting technique is virtually the only way Quantovac analysis could have been made on bloomery iron, since such samples are normally too porous to give a reliable result. The following table shows the results obtained. Clearly with the exception of nickel the two materials are very similar.

%	Newcastle Bloom (No. 6)	Muncaster Bloom
C	0. 21	0. 02
Mn	0. 01	0. 01
S	0. 039	0. 017
P	0. 08	0. 06
Si	0. 02	0. 01
Ni	0. 13	0. 02
Cr	0. 01	0. 01
Mo	0. 02	0. 01

DISCUSSION

The characteristic feature of all bloomery iron is its heterogeneity, and the two samples examined in the present investigation were more or less typical in this respect. It is usual to find carbon segregated and rising to very high levels in some parts of the bloom whilst being very low in others.

In nature and microstructure the modern bloom would appear to be very similar to the post-Medieval one, and therefore it would be possible to say that the basic process has been reconstructed quite accurately. The only way in which the modern bloom appears to differ from the post-Medieval one is that on average the degree of carburization is somewhat higher and that there is rather less porosity on a macroscopic scale. It is possible, therefore, that the modern furnace may have operated at a slightly higher temperature than the post-Medieval one. However, to be absolutely certain on this point it would be necessary to carry out many more sections, since the porosity normally varies considerably from place to place in unconsolidated blooms.

CONCLUSIONS

The iron produced by the modern reconstruction of a bloomery furnace appears to be very similar to that produced by a post-Medieval furnace.

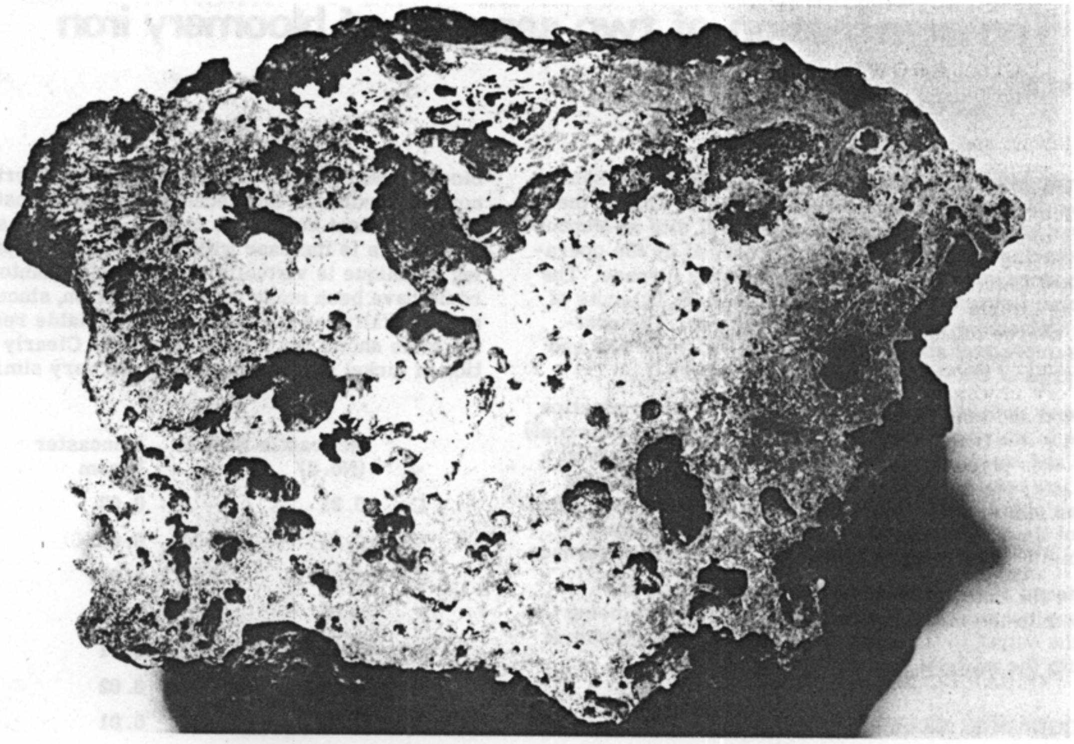

Fig. 1 — Newcastle bloom, deep etched × 1 approx.

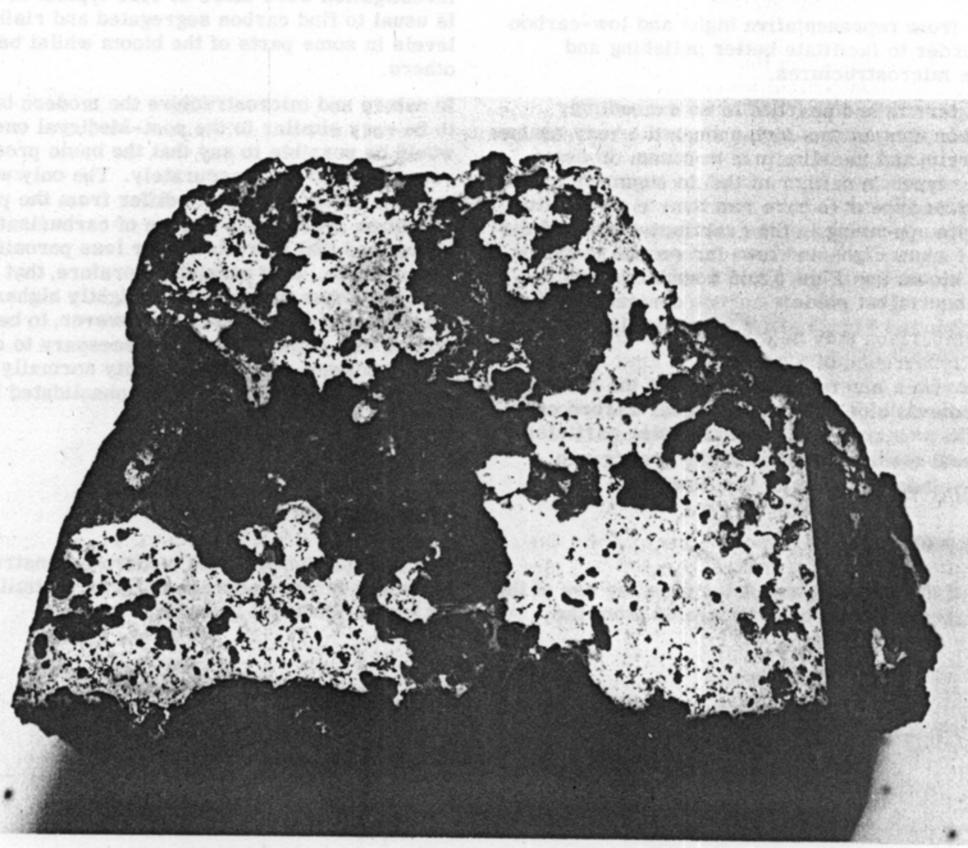

Fig. 2 — Muncaster bloom, deep etched × 1. 25 approx.

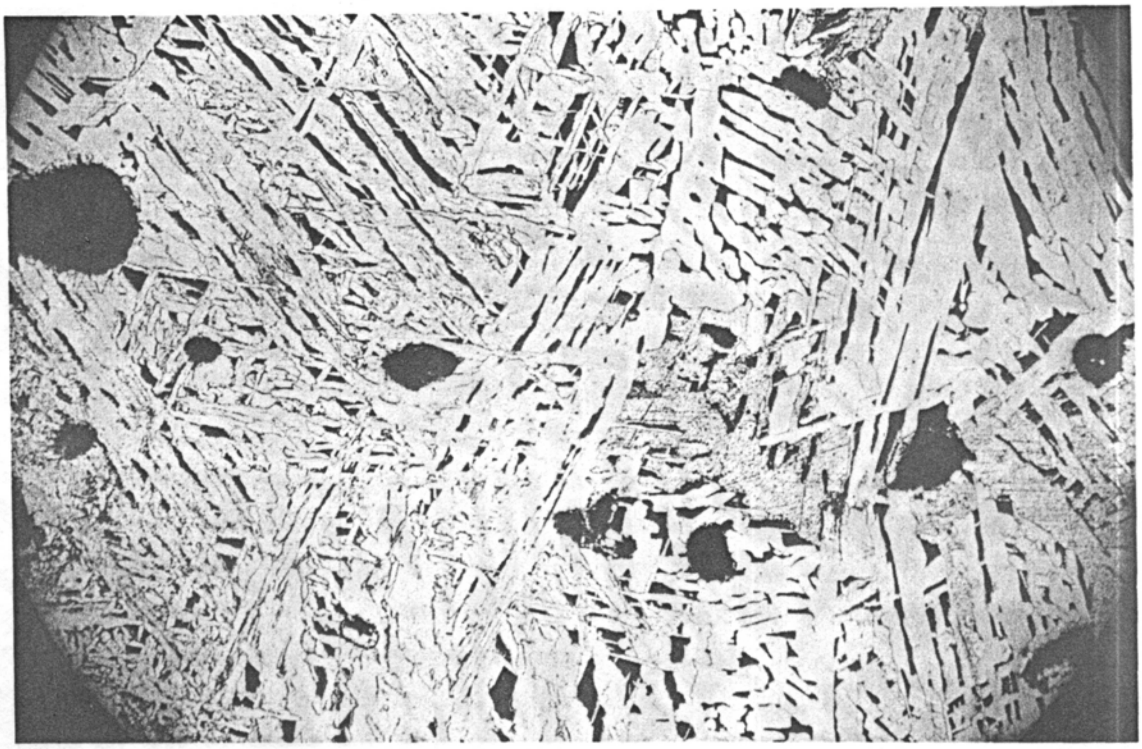

Fig. 3 — Low-carbon area of Muncaster bloom × 50

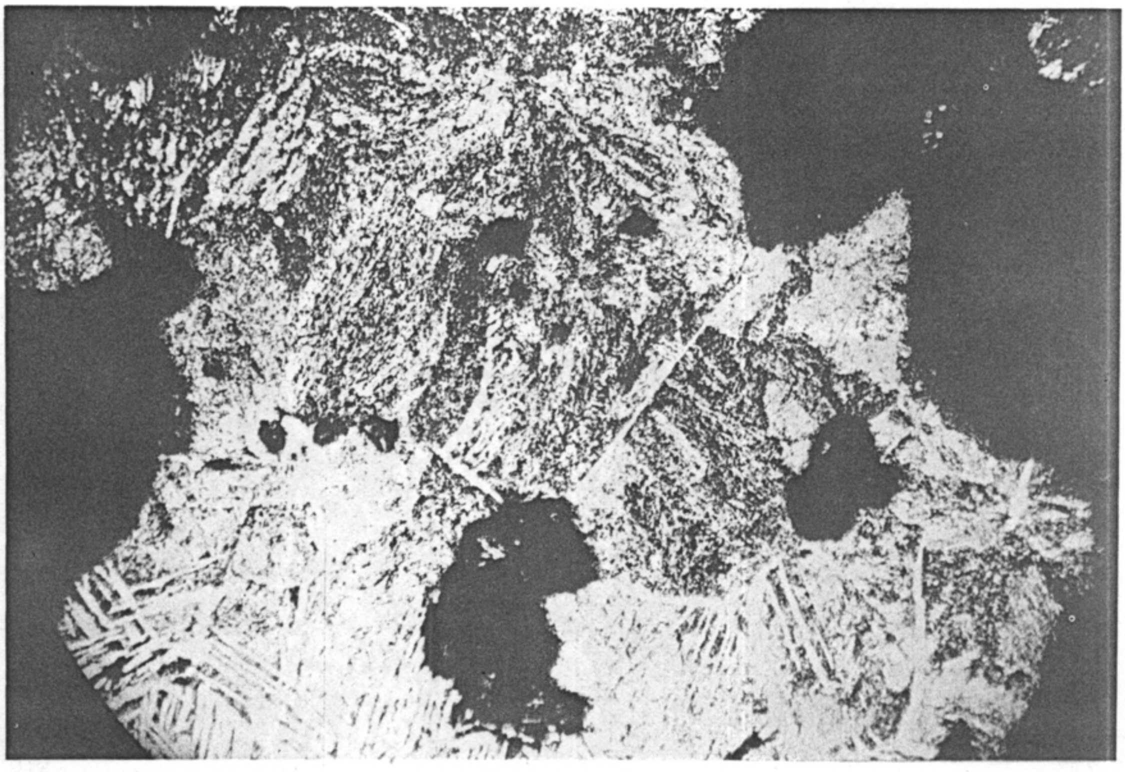

Fig. 4 — High-carbon area of Muncaster bloom × 50

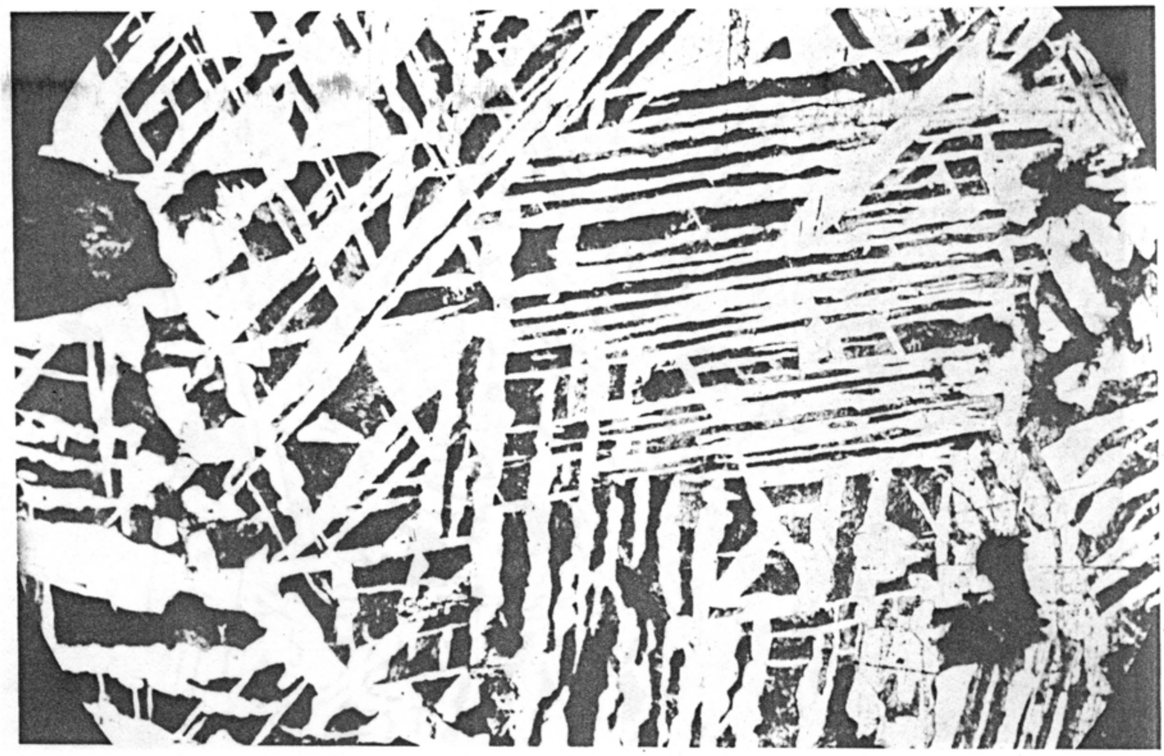

Fig. 5 — Low-carbon area of Newcastle bloom × 50

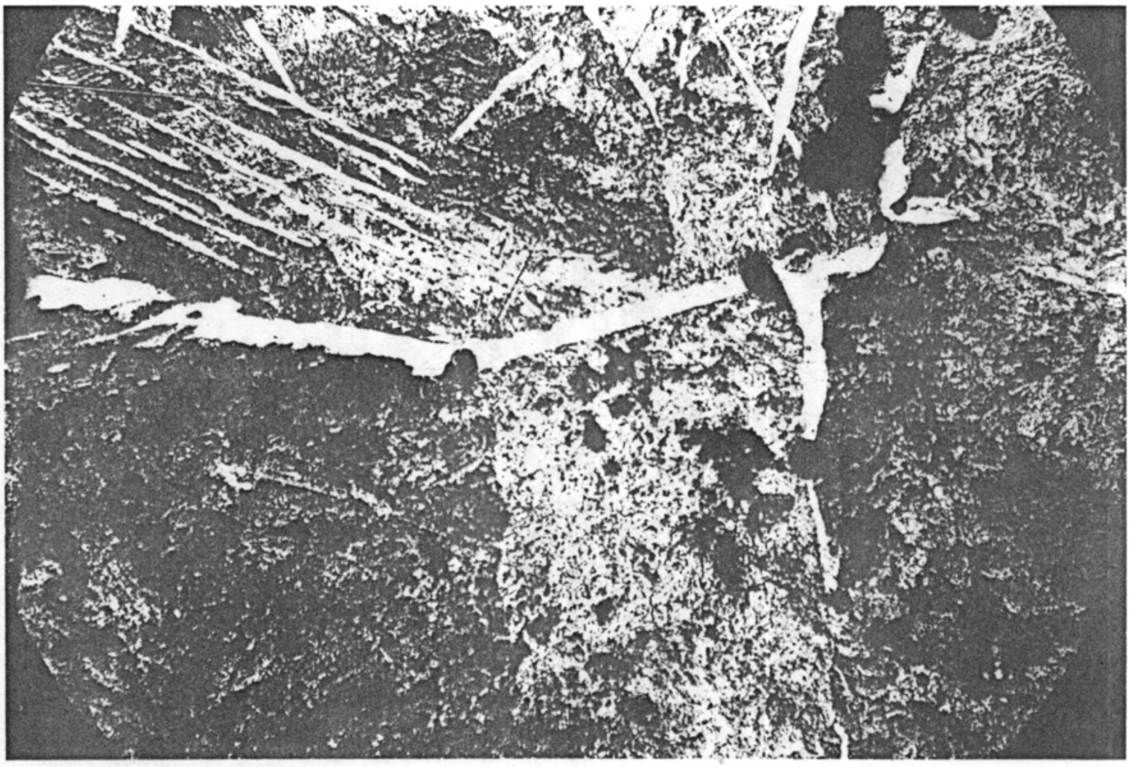

Fig. 6 — High-carbon area of Newcastle bloom × 50

Further analyses of the bronze coinage of the Roman Emperor Maxentius, AD 306–312

LAWRENCE H. COPE AND HARRY N. BILLINGHAM

An earlier exploratory study of the chemical composition of the bronze coinage of the independent Emperor Maxentius (published in 1969 in Vol. 3, No. 2, of the Bulletin) was based upon only eight random specimens of the coinage which were available at the time for destructive analysis. These provided a somewhat uneven and inadequate chronological representation of the products of four of the five Maxentian mints but, nevertheless, it was possible to discern a consistent fineness pertaining to the varied argentiferous bronzes, and definite trends towards the use of more leaded alloys by the mints of Rome and Ostia during the later years of Maxentian control.

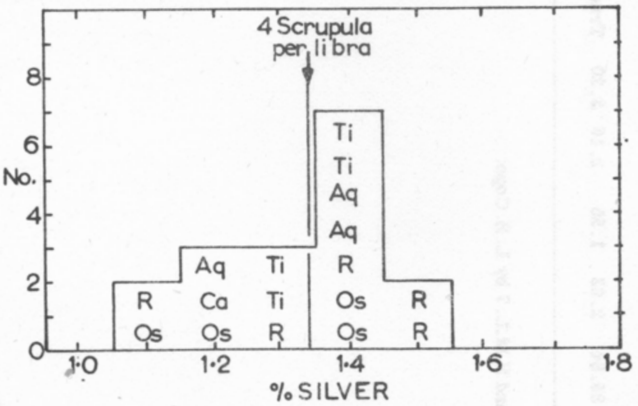

Fig. 1 — Assays of Maxentian coinage

More recently, through the kind interest and with the generous help of Dr A Jeločnik of the Narodni Muzej, Ljubljana, Jugoslavia, it has been possible to determine, more systematically, the alloy compositions of both early and later issues of all four Italian mints; a coin minted at Carthage shortly before the closure of that mint towards the end of AD 307; and a coin minted at Siscia contemporaneously with the mid-reign issues of the Maxentian mints.

The coin analyses of this series are given in Table I, and certain features of these are also illustrated in Figs. 1, 2, and 3. The dates of issues listed are ones quoted by Dr Jeločnik; these are rather more precise than those given in the standard work of reference ('Roman Imperial Coinage', Vol. VI) in which the coins are identified.

With only one exception (a patinated coin, N.M.L. 8) the coins were coated thinly with green corrosion products which were all found to consist mainly of basic copper carbonate. Beneath the corrosion lay thin silver 'washes' which were easily removed by brushing. The surfaces were filed clean, and quarter-coin sectors were prepared for H. N. Billingham to analyse. Duplicate (half-coin) samples were later assayed for silver, tin, and lead, in the case of the two most highly-leaded alloys whose microstructures showed the most marked heterogeneities.

The new analyses do not necessitate any amendments to the interpretations of the earlier results. In fact they provide considerable confirmatory evidence based on material which extends the range and chronological depth of analysed samples.

FINENESS

The seventeen assays of the Maxentian coinage tabulated in this and in the authors' previous work are represented diagramatically in Fig. 1. The histogram reveals a standard of 4 scrupula of silver per libra of bronze coinage alloy, which was maintained rather better at the two northern Italian mints of Ticinum and Aquileia than at either Rome or Ostia, where the base alloys ranged wider in composition, with respect to tin and lead proportions.

There is the possibility that, in the later years of Maxentian rule, the fineness standard was not so carefully maintained; indeed, it might have been reduced deliberately to 3 scrupula per libra during the last two years. The duplicate assays of larger samples taken from the two alloys with the lowest silver contents, however, gave slightly higher results. These certainly confirm suspicions that segregation of the insoluble lead-phase can profoundly affect the distribution of silver within the coins themselves; but, for the present, it is assumed that the coins N.M.L. 6 and N.M.L. 7 really belong to an intended 4-scrupula standard.

PROPORTIONS OF TIN AND LEAD

Figures 2, 3, and 4 reveal the related proportions of tin and lead found in all the Maxentian folles which the authors have analysed to data, and show the preferred alloying practices adopted at the different mints.

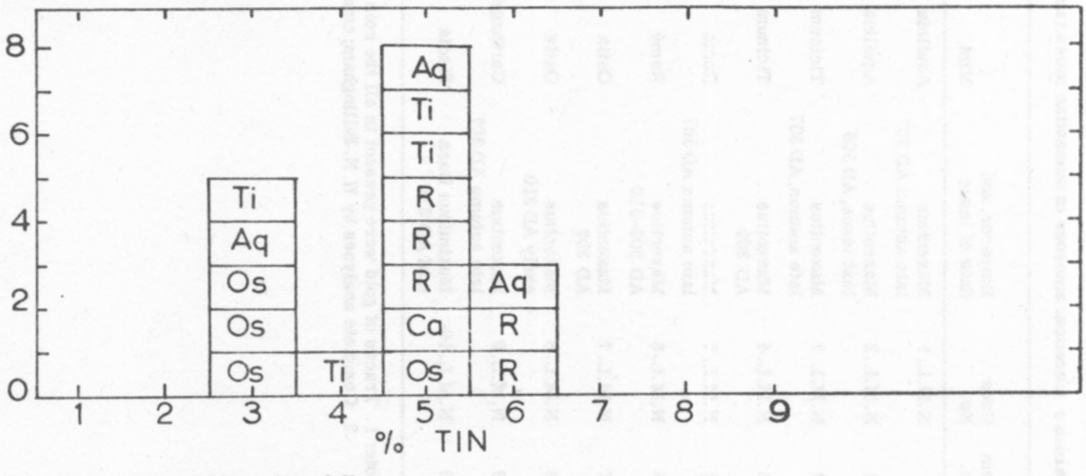

Fig. 2 — Tin contents of Maxentian folles

TABLE I **Chemical analyses of Maxentian folles (and one from Siscia) minted between AD 306 and 312**

Item No.	Code No.	Emperor, and date of issue	Mint	Coin Weight, g	Reverse Type	Chemical Analyses, wt-%									Sample	Coin reference in R.I.C. vi
						Copper	Tin	Silver	Lead	Iron	Nickel	Cobalt	Zinc	Total		
1	N.M.L. 1	Maxentius late autumn AD 307	Aquileia	6.24	CONSERV/VRB SVAE	87.17	5.37	1.40	8.00	0.03	0.03	0.02	0.01	100.03	1	Aquileia, 116
2	N.M.L. 2	Maxentius last issue, AD 309	Aquileia	6.19	CONSERV/VRB SVAE	86.60	6.02	1.47	5.83	0.02	0.01	0.02	0.02	99.99	1	Aquileia, 113
3	N.M.L. 3	Maxentius late autumn, AD 307	Ticinum	6.54	CONSERVATORES VRB SVAE	88.85	3.48	1.44	5.79	0.02	0.02	0.03	0.02	99.65	1	Ticinum, 84a
4	N.M.L. 4	Maxentius AD 309	Ticinum	6.10	CONSERV/VRB SVAE	86.88	5.09	1.37	6.23	0.03	0.02	0.01	0.01	99.64	1	Ticinum, 108
5	N.M.L. 5	Maxentius late autumn AD 307	Rome	6.42	CONSERVATO/RES VRB SVAE	83.58	5.23	1.53	9.35	0.03	0.03	0.01	Trace	99.76	1	Rome, 165
6	N.M.L. 6	Maxentius AD 309-310	Rome	6.62	CONSERV/VRB SVAE	80.79	5.36	1.08	12.31	Trace	0.02	0.03	0.01	99.60	1	Rome, 210
						—	5.21	1.19	12.21	—	—	—	—		2	
7	N.M.L. 7	Maxentius AD 308	Ostia	5.70	AETE/RNITAS A/VG N	86.47	3.52	1.16	8.39	0.03	0.03	0.05	None	99.65	1	Ostia, 16
						—	3.13	1.23	7.88	—	—	—	—		2	
8	N.M.L. 8	Maxentius early AD 310	Ostia	6.43	VICTORIA/A AE/TERNA AVG N	90.82	3.40	1.47	4.23	0.01	0.02	0.03	0.02	100.00	1	Ostia, 54
9	N.M.L. 9	Maxentius late autumn AD 307	Carthage	5.93	CONSERVATO/RES KART SVAE	81.25	5.45	1.20	11.90	0.03	0.03	0.03	0.01	99.90	1	Carthage, 60
10	N.M.L. 10	Maximinus Daza mid AD 310	Siscia	6.81	GENIO AV/GVSTI	89.84	2.92	1.55	2.16	3.20	Trace	0.02	0.04	99.73	1	Siscia, 207c.

Note: 1. Traces of gold were present in all the coin alloys.
2. Complete analyses by H. N. Billingham; confirmatory asseys on half-coin samples of N.M.L. 6 and N.M.L. 7 by L. H. Cope.

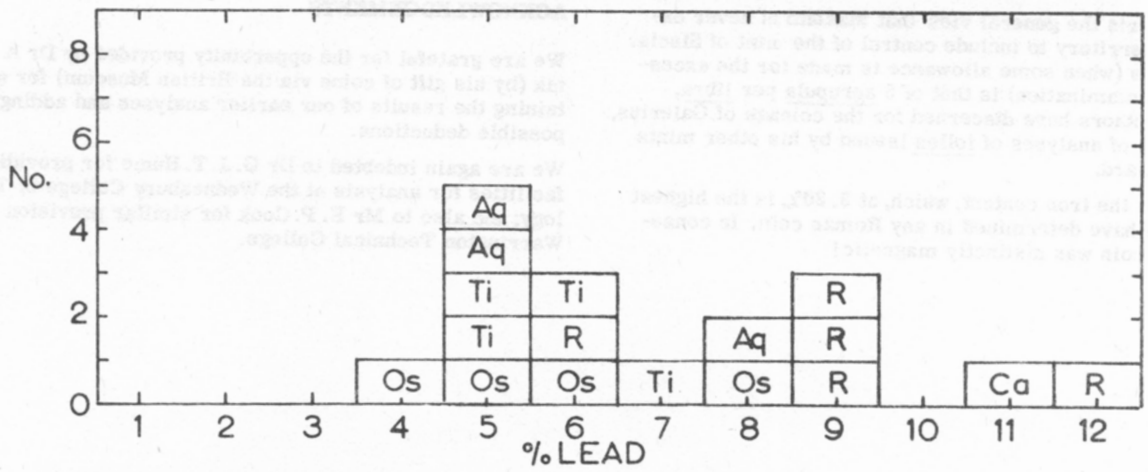

Fig. 3 — Lead contents of Maxentian folles

The histogram for tin (Fig. 2) suggests two preferred composition levels, which appear to be based on additions of either 12 or 18 scrupula of tin per libra melt (Fig. 4). The mints of Carthage and Rome seem to have had a consistent preference for the higher of the two typical tin additions, but Ticinum, Aquileia, and Ostia obviously worked to both standards, even in one officina.

The lead alloying additions (Fig. 3) appear to have been at three (or maybe five) different levels, corresponding with amounts of 12, 18, 24, 30 and 36 scrupula per libra. The most highly leaded alloys are those minted at Carthage and Rome, and at an earlier Greek-numbered officina of Ostia. Figure 4 reveals how much the combined tin and lead proportions of these coinages depart from the equal additions made to the alloys of the early larger folles, and from some in the Maxentian series.

The Carthaginian coin is the earliest example yet encountered of a very highly leaded follis alloy. This alloying characteristic is to be found at later dates, with folles of smaller module, spreading to Rome, Ostia, Arles, and thence to most of the western mints under Constantine's control.

The analyses are indicative of the mint-personnel of Carthage having been transferred to Ostia via Rome, and taking their preferred alloying practices with them. Rome continued to find the leaded alloys more suitable for the 1/48 libra folles manufacture, and the founding of Ostia (probably with the Carthaginian Greek-numbered officinae contingents) does not seem to have led to a return to earlier traditional alloying practices at Rome. Ostia, itself, may have been influenced in like manner, for the later Latin-lettered officinae produced some alloys bearing remarkable resemblances to the coinages of Ticinum and Aquileia. It is suggested that, in early AD 310, the mint at Ostia (and perhaps at Rome also) was supplemented by the transfer of the personnel of Ticinum and Aquileia coincident with the cessation of Greek markings and the permanent introduction of the Latin ones.

THE MINT OF SISCIA

The analysis of the Siscian follis is of special importance and significance. Its fineness, and the low proportions of the tin and lead components, prove a metallurgical independence

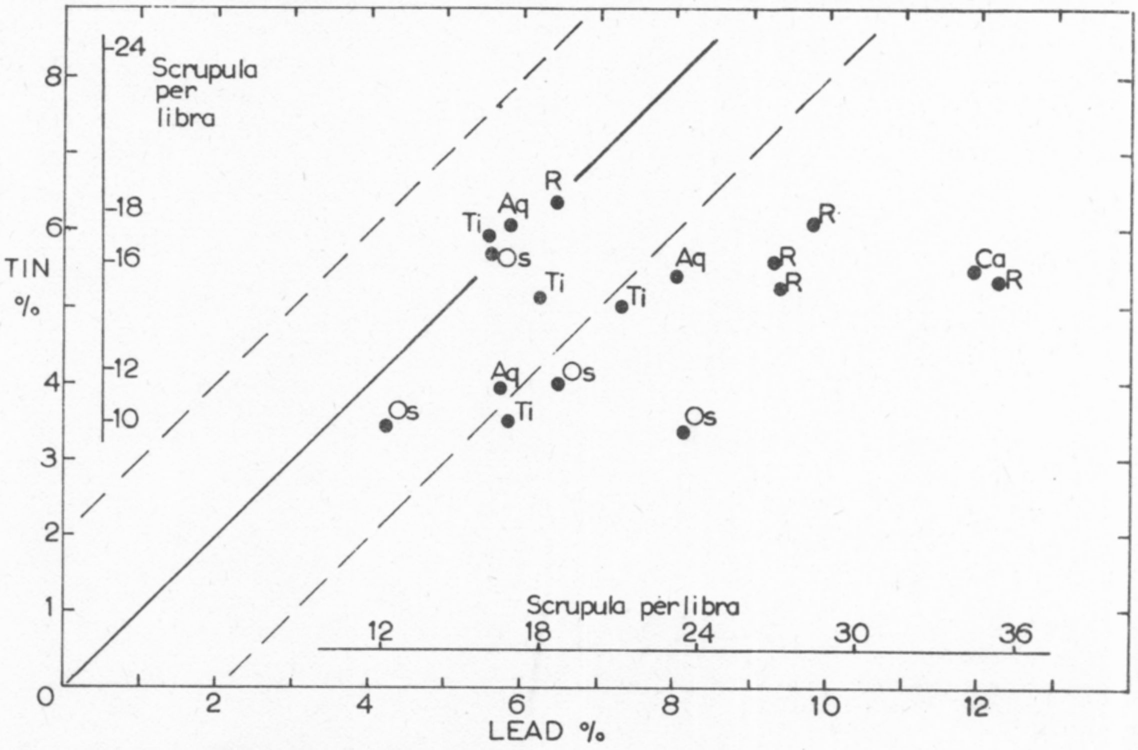

Fig. 4 — Lead/tin ratios of Maxentian folles

which supports the general view that Maxentius never extended his territory to include control of the mint of Siscia. The fineness (when some allowance is made for the excessive iron contamination) is that of 5 scrupula per libra, which the authors have discerned for the coinage of Galerius, on the basis of analyses of folles issued by his other mints to the eastward.

An oddity is the iron content, which, at 3.20%, is the highest the authors have determined in any Roman coin. In consequence the coin was distinctly magnetic!

ACKNOWLEDGEMENTS

We are grateful for the opportunity provided by Dr A Jeločnik (by his gift of coins via the British Museum) for ascertaining the results of our earlier analyses and adding to the possible deductions.

We are again indebted to Dr G. J. T. Hume for providing the facilities for analysis at the Wednesbury College of Technology; and also to Mr E. P. Cook for similar provision at the Warrington Technical College.

Examination of copper alloy tools from Tal y Yahya, Iran

R. F. TYLECOTE AND H. McKERRELL

Tal y Yahya is a tepe or mound in the Soghun valley 200 km south of Kerman in Iran. It is 190 m dia. and 19 m high and is the largest and most imposing of the pre-Islamic settlement mounds in south-east Iran. It has recently become the subject of excavation by Professor C. C. Lamberg-Karlovsky of Harvard, who has found levels dating from about 4500 BC to AD 200. The four objects discussed in this report come from the Yahya period and cover the range 3800 BC to 3000 BC. Approximate dates are 3800 BC for the chisel and the awl, 3500 BC for the spatula, and 3000 BC for the dagger. It is interesting that it is the latter that is the most corroded, possibly because it has a significant tin content while the others are arsenical coppers.

Metallographic examination (see Fig. 1)

(A) Spatula. This weighed 65 g and had an even green patina, covered in a few places with a limy deposit. The blade had been forged flat but the shank had a rectangular section which had been doubled over at the head. A microsection was taken from the edge of the blade and showed cuprous oxide globules elongated in the direction of the edge. Upon etching in ferric chloride a faint trace of coring became apparent, together with a fine evenly dispersed precipitate. The grain structure was coarse and equiaxed with twins. The hardness was 97 HV 1.

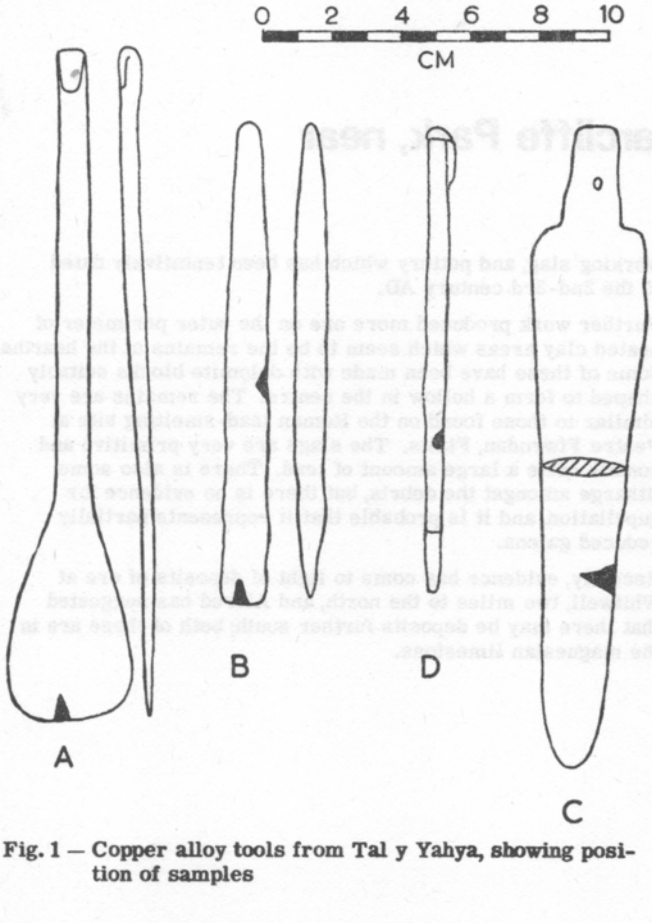

Fig. 1 — Copper alloy tools from Tal y Yahya, showing position of samples

(B) Chisel. This weighed 95 g and was in a remarkably good state, with a few green encrustations and some limy deposit. The central section was rectangular and had a slight twist, suggesting that it had been used like a screwdriver. There was no mushrooming of the chisel-shaped head, which suggested that it had not been used as a cold chisel directly hit by the hammer but as a wood chisel with a wooden handle. Two sections were taken; one was from the sharper of the two edges which had a limy coating and the other from the centre of the shank.

The edge showed an enormous quantity of elongated black inclusions strung out almost as laminations going right up to the edge. On etching, heavy concentrations of slip lines were visible, but there seemed to be a complete absence of any twins. Grain boundaries were few and the grain size seemed to be very coarse. The hardness was 163.

The centre section showed rounded inclusions (seen end-on), and some residual coring and second phase. Again there were few grain boundaries and plenty of slip bands. The hardness was 148.

(C) Dagger. This weighed 85 g and was in a very corroded condition; a section near the middle showed only a small amount of residual metal in the centre. This had a recrystallized grain structure with preferentially corroded slip bands. Very fine slag stringers were visible in the centre of the cross-section. The grains were large and equiaxed with twins and slip bands. The hardness was 105.

(D) Awl or nail. This had a square section and weighed 29 g. The point appeared to have been forged round, but the head had been folded over like the head of the spatula and then mushroomed, showing that it had been hit with a hammer. There was no green encrustation but some limy deposit. The tip was blunt and the end was possibly missing but otherwise the tool was in good condition. The microspecimen was cut from the square section near the tip.

This was by far the most coppery of the four tools and therefore appeared to be the least alloyed, which was borne out by the analysis. It had some inclusions of cuprous oxide and a fine precipitate like the spatula. Owing to its purity it etched very slowly and showed a fine equiaxed grain structure with no residual coring. There were a few bent twins, and triangular etch figures were easily produced showing evidence of cold work. The hardness was 106.

Analysis

The composition of the specimens was determined on the swarf resulting from the cutting-out of the specimens for micro-examination. In the case of the badly corroded dagger (C) this would be largely corrosion product, but in the other cases it was almost all metal with a small amount of surface patina.

Samples of metal from the four implements were analysed as-received, both qualitatively by arc spectrograph and quantitatively by x-ray fluorescence. Unfortunately all the specimens contained some mineralized component which it was impractical to remove, and the quantitative results must therefore be interpreted with caution.

The qualitative analysis showed that arsenic was present as a minor component in all four implements and that tin was similarly present in sample C (dagger) only. A trace of lead (approx. 0.05%) was found in all four samples but no nickel or bismuth (<0.01%). The tin contents of samples A, B, and D were all less then 0.01%. Antimony was not detected and would be present below 0.1% for all samples.

Quantitative results determined are as below—

	% As	% Sn
Sample A: Spatula	1.7	<0.01
Sample B: Chisel	3.7	<0.01
Sample C: Dagger	1.1	3.0

Sample D: Awl	0.3	<0.01

Considerable variation in these results was observed for differing portions of the same sample and, as stressed above, they should be interpreted appropriately.

Conclusions

The analyses show that all the objects except the awl have significant alloying elements. The arsenic would not be added but would arise from judicious selection of ore. It is possible that the As content of the awl was originally higher, but that some of the As has been lost during working. It is now an impure copper with cuprous oxide both as coarse inclusions and as a fine precipitate. It has been both hot- and cold-worked, and the relatively high hardness is the product of both the composition and the working that it has received.

The chisel is a very modern-looking implement and the hardness of its edge, 163 HV 1, is equivalent to that of a modern medium-carbon steel as forged but not heat-treated. The edge would not seem to have been used to cut anything hard as it shows no deformation. The hardness has been achieved by cold-hammering after some prolonged heating to remove most of the segregation that arises on casting. Either the chisel has not been used or it has had the back end embedded in a wooden handle like a wood chisel. It would make a very efficient tool.

Only the blade of the spatula was examined, and this was mainly formed by hot working. The hardness is less than that of the awl, yet the As content is appreciably higher: this is because it has received no cold work, which suggests that it was not intended as a cutting implement.

The dagger was the most corroded of all the implements and the only one to contain any tin. The analysed tin content is in agreement with the hardness and the structure of the residual metal and there is no reason to suppose that the metal was very different from the corrosion product except for the presence of oxides and carbonates in the latter. This, therefore is one of the many arsenical low-tin bronzes which appear in many parts of the world in the transitional period between arsenical copper and non-arsenical tin-bronze. As in this case, they are made by forging rather than casting, as in the tin-bronzes. The dagger should have been capable of work-hardening as much as the chisel, and it is probable that the edge was a good deal harder than that of the central spine.

All the implements have been made from smelted, cast, and forged copper or copper-base alloy, reheated and hot-worked. Some of the edges of the tools have been cold-worked to a considerable extent, probably resulting in a reduction of thickness of 50% or more. The maximum hardness achieved was at the edge of the chisel.

The technique is typical of the Copper or Early Bronze Age. It is possible that the tools may have been made elsewhere; the nearest known copper deposit is at Rafsanjan, about 100 km west of Kerman. Nothing is known of the composition of this deposit, but it is clear that the copper used did not have an appreciable nickel content like so many of the Near Eastern artifacts of this period. None of the implements could have been made of native copper.

Romano–British lead working at Scarcliffe Park, near Chesterfield

This site is situated on the magnesian limestone near Langwith in eastern Derbyshire, rather outside the better known lead mining area near Matlock. The National Grid reference is SK 512 710. It has recently been the subject of excavation by Harry Lane, who is a tutor in Archaeology for the Adult Education Department of Nottingham University and who has been working on Romano-British native rural settlements. The smelting area that is being excavated is in an area of woodland, and the nearest recently exploited lead deposits lie some 15 miles west.

A small fragment of refined lead was found in 1967 in a stone-built irregular oval-shaped enclosure. Field work in 1968 revealed a large quantity of lead slag scattered over about 670 yd^2. A trial trench produced a solid mass of slag and charcoal and lumps of heated ore with visible galena content. In an area to the south of this was evidence of more lead-working slag, and pottery which has been tentatively dated to the 2nd-3rd century AD.

Further work produced more ore on the outer perimeter of heated clay areas which seem to be the remains of the hearths. Some of these have been made with dolomite blocks suitably shaped to form a hollow in the centre. The remains are very similar to those found on the Roman lead-smelting site at Pentre Ffwrndan, Flints. The slags are very primitive and contain quite a large amount of lead. There is also some litharge amongst the debris, but there is no evidence for cupellation, and it is probable that it represents partially reduced galena.

Recently, evidence has come to light of deposits of ore at Whitwell, two miles to the north, and Aldred has suggested that there may be deposits further south; both of these are in the magnesian limestone.

Work in Progress

CHINGLEY FORGE AND FURNACE—SUMMER 1970

At Chingley Furnace, (Nat. Grid Ref. TQ 684 327; date range pre-1565-c. 1588), considerable progress was made in 1970: the main furnace structure was cleared down to the level of the bellows area floor, and the major features are now clear. The furnace is a square stone structure with solid walls on the north and west sides. The hearth is in a relatively good state of preservation, certainly far more complete than at Panningridge, Sussex (TQ 687 175). The lining is in position, badly caked with slag, and a preliminary estimate suggests that, when abandoned, iron-making capacity must have been a third or nearer a quarter of the original. Further work is needed to reach the level of the hearth bottom. The 'pillar' of the furnace, between the tuyere and casting arches, survives but is remarkable for its small size, which must have made this, the south-east corner of the furnace, particularly fragile. The bellows appear to have been mounted to the east of the furnace, and at this stage of work are indicated by a large beam in a position appropriate to the front of the bellows and, perhaps less reliably, by a large timber, apparently the collapsed camshaft, close to the dam. The casting floor, probably to the south of the furnace, has been partially excavated, but much remains to be done. A small roughly-walled area immediately to the west of the furnace appears to be the remains of a store shed: indications were fragmentary. The wheel-pit area is now fairly clearly established, to the south-east of the furnace, in line with a disturbance in the front slope of the dam and, away to the south-west, a strip of marshy ground in the wood indicating a tail-race. Accumulations of silt will prolong work in this area, but the high level of the water table makes well-preserved timber likely.

Work in 1971 will involve

(i) The completion of excavation immediately around the furnace
(ii) The excavation of the wheel pit
(iii) Measuring the furnace, and dismantling to check for underground drainage of the hearth area, and any earlier structures.

At Chingley Forge (TQ 682 336; date range: ?medieval—early 18th-century), what was planned as a fairly brief operation to delimit the western extent of the forge building soon became complicated by the appearance of earlier periods. An area to the west of the timber wheel pit recorded in 1969 was mechanically stripped, and features belonging to this period were investigated. To the west of the timber wheel pit were, respectively, a small wooden foundation for an anvil and the sill-beam for the west wall of the forge. The tailrace of the wheel pit had been modified to include an offset and here an overshot wheel had been mounted; this would operate the chafery bellows, and fragments of the wheel were in position. The filling of the tailrace provided ample finds to date operation and silting to the late 17th and early 18th centuries; particularly noticeable were the quantities of iron objects, suggesting that secondary metal manufacture took place on the site; door furniture, nails, knife blades, and scrap both ferrous and nonferrous were found.

Two earlier periods were recorded, immediately to the west of the timber wheel pit referred to above. The more recent stage was represented by a massively built wheel support, of particularly fine construction, in which appear to have been set two waterwheels, mounted abreast. This had been partly destroyed for the building of the later race. At a lower level still was a narrow channel, containing fragments of an overshot wheel, and a sherd of stamped Rye pottery appropriate to the period before 1500; a jug-handle fragment of generally medieval appearance was also present. This sample is, however, too small for any certain designation of this structure to the medieval period.

These features were not fully excavated, and, particularly in view of the doubts about the earliest period, much more work must be done in 1971.

D. W. CROSSLEY

HOLBEANWOOD, SUSSEX

Excavations continued at the Holbeanwood site in Ticehurst, Sussex (TQ 664 305) at Easter, Spring Bank Holiday, and July/August 1970 for a total of 16 days.

The area first explored in the winter of 1968-1969 was considerably extended. The original course of the small stream running through the site was established. This had been partly filled in with several large deposits of slag, which had ultimately silted up to block the bed completely; the stream then appears to have taken a new course, about 10m to the north west, and in doing so removed the entire west side of the timber building in which six furnaces were discovered in 1968-1969.

Two further sites were explored, 30m north and 20m north-east of the original area (trenches II and IV respectively). Trench II had been test-trenched at Easter 1969, when a gully was found, filled with slag and running roughly east, presumably to join the original stream. A small lump of roasted and sized iron ore suggested that either ore-roasting or smelting were carried out in this area.

In Trench IV, the hearths of two more iron-smelting shaft furnaces were discovered, bringing the total at the site so far to eight. Like those found in 1968-69, these were about 30cm internal diameter, and made of clay, and both had been relined at least once. They were associated with another thick dump of slag, in what is believed to be the filled-in stream bed. Unfortunately, considerable earth disturbance resulting from levelling and ploughing in the past decade has made the use of resistivity surveying unreliable, whilst the presence of large amounts of iron slag rule out magnetometer surveys, and so excavation is essential to establish these points.

As in the earlier campaign, finds have been scanty. Pottery is very rare, and is largely of very coarse wares. These continue to show similarities with material from the Bardown II-IIIrd century AD settlement a mile away. The quality and rarity of the pottery finds are consistent with the view that the Holbeanwood site was a satellite working place associated with the Bardown settlement, where industrial operations are presumed to have ceased by the end of the IInd century, but which was occupied until the mid-IIIrd century. The Roman dating of Holbeanwood was conclusively proved by the find of a much worn but still identifiable piece of samian pottery in a stratified layer of Trench II in July 1970.

The 'satellite workplace' theory received further support during 1970. Fieldwork in the neighbourhood of Bardown (partly observations on the trench for the natural gas pipeline that crosses the area) revealed four new sites that have produced bloomery slag, all to the south of Bardown and ½-1½ miles from the settlement. This brings the total of such sites (including Holbeanwood) to seven.

During 1971, work at Holbeanwood will continue in Trenches II and IV, which are both potential iron-smelting and iron-working complexes.

H. F. CLEERE

Abstracts

General

Metals in the ancient world. M. Finley. (J. Roy. Soc. Arts, 1970, Sept., 11 pages). The author is Professor of Ancient History in the University of Cambridge. This paper is based mainly on classical written sources and on the interpretation of scenes on Greek pottery. It deals more with the social aspects of the metal worker than with the more technological side.

Investigations on high-nickel steel in antiquity. J. Piaskowski. (Hutnik, 1970, 37,(2), 83-90) [In Pol.] Arguments on the meteoric origin of iron with a high nickel content in use in antiquity are discussed. The results obtained by metallographic examination of ancient products manufactured of such iron are described. The author presents arguments for the hypothesis that high-nickel steel of antiquity was man-made (among others by the Chalybes, the tribes of primitives in Asia Minor mentioned in classical literature) and not of meteoric origin.

A note on the structural antecedents of the I-beam. Harold Dorn. (Tech. Cult., 1968, 9, 415-418). The use of iron beams in Greek and Roman masonry structures.

Structural antecedents of the I-beam, 1800-1850). R. A. Jewett. (Tech. Cult. 1967, 8, 3, 346-361). It is shown that the necessity for fireproof construction prompted the use of cast-iron beams by 1800; a small bottom flange was added only to serve as a ledge to support the brick arches of the floor and this functional purpose was adopted for form. In 1830 an I-shaped railroad rail was first manufactured, to eliminate expensive cast-iron chairs. Further advance took place in 1845 in tests of wrought iron before building the Britannia and Conway bridges. Such wrought iron beams proved to be the best material available and a brief evolution modified the original rectangular tubular form (the box girder) to the present-day plate girder.

The great hot-blast affair. R. D. Corrins. (Ind. Arch., 1970, 7, (3), 233-263). The paper discusses the dispute between Neilson and Baird over the rights of hot blast in the blast furnace.

The nailmakers. A. F. Moseley. (J. West Mid. Reg. Studies, 1968, 2, Dec., 6-38) The early history of nailmaking, including the production of Roman nails etc., is briefly described and a comprehensive review of the 19th century manufacture of nails, particularly in the West Midlands, is presented. A description of a nailer's shop is given and details of the nailer's block, anvil, and other tools are given. The types of nails illustrated are Roman nails, hand-wrought nails, and cast nails. Some discussion of the 19th century nail trade is presented and background information regarding the home life of the nailer given. The history of the slitting mill, which had such an important effect on the hand-wrought nail trade, is briefly described and an old slitting mill is illustrated. (24 refs.)

British Isles

Report on a Romano-British settlement and metallurgical site at Vespasian Farm, Green Ore, Somerset. H. W. W. Ashworth. (J. Mendip Nature Research Committee, 1970, March, 17 pp.) This excavation located an iron- and a lead-smelting area. Lead smelting was indicated by lumps of litharge, lead slag, and lead ore. The silver content of the litharge was 1-2 oz/ton (0.004-0.008%) and that of the galena 0.003-0.01% Ag per ton lead. The silver content of the metal itself varied between 0.0014% and 0.019%, the latter probably representing the original non-desilverized lead. The iron-smelting area had a 2 ft deep by 4 ft wide trench going through it in which roasting is thought to have been carried out. Crushed yellow iron ore (about 10 lb) was found on one side of the trench. Several thousand pieces (175 lb) of iron cinder and slag, together with burnt clay, were found. A coin dated to AD 169-180 occurred in stratified levels of this area.

Lead mining in 1768; old records of a Scottish mining company. W. S. Harvey. (Ind. Arch., 1970, 7(3), 310-318). Some details, mainly social, of a short period in the history of a famous lead and gold mining and smelting area.

John Knowles and the wrought-iron tube fitting trade. K. W. Knowles. (J. West Mid. Reg. Studies, 1968, 2, 77-91). The history of a Black Country firm specializing in making tube fittings from 1802 onwards.

An historical survey of the Cleveland ironstone industry. S. K. Chapman. (Trans. Teesside Indust. Archeol. Group, 1969, 1, (1), pp. 15). An interesting description is given of the iron industry in the North East Coast area from about 1745, when nodules of ironstone were first found on the shore at Robin Hood's Bay, to 1883, when the output of Cleveland ironstone reached its maximum 6¼ M tons. By 1957, however, output had slipped to only 556 000 tons and the Lingdale mine closed in 1962, the Kilton in 1963, and North Skelton in 1964. Several of the prominent companies of the 19th century are mentioned including the Tyne Iron Co., the Birtley Co., The Wylam Iron Co., Bolckow, Vaughan and Co., the Skinningrove Iron Co., and the Ferryhill Iron Co.

Gjers, Mills and Co. Ltd: A case study of a Victorian ironworks. B. E. Mackin. (Trans. Teesside Indust. Archeol. Group, 1969, 1, (1), pp. 7) The founding and development of Ayresome Ironworks by Gjers, Mills and Co. Ltd. is described and the background of industrial expansion and technological development on Teesside in the middle of the 19th century is discussed. A description of the Ayresome ironworks is given and some of the blast furnaces and the blast engine are shown.

Europe

The origin and evolution of ferrous metallurgy in Europe. J. R. Maréchal. (Janus, Leiden, 1969, 46, (2), 86-97). [In Fr.]. A general account of the minerals and techniques used up to modern times. It concludes with the results of modern experiments designed to reproduce obsolete processes.

New contribution of Czechoslovakian archaeology towards the history of ferrous metallurgy in Europe. R. Pleiner. (Atti VI Congr. Internat. Sci. Preistor. Protoistor, 1966, 70-74) [in Ger.] A brief survey is given of studies covering the period from the Early Iron Age to the Middle Ages.

The appearance of iron production on shore sites in Savoy during the last phase of the final Bronze Age. R. Laurent. (Bulletin Mensuelle Société Linnéene Lyon, 1968, 37, (2), Feb, pp. 12.) [In Fr.] Bronze objects found alongside the shores of the Lac du Bourget (Savoie) have been found to have iron fittings. The results of analyses are given and it is tentatively proposed that iron production c. 750 BC in the upper Rhône basin is probably the result of 'acculturation' from Northern Italy rather than an 'invasion' from the Rhine. (31 refs.)

Princely and monastic forges; a glimpse of ferrous metallurgy in Lorraine in the 12th and 13th centuries. G. Hansotte. (Rev. Hist. Min. Mét., 1970, 2, 3-20). [In Fr.]. Mainly about the ores used, their types, and location.

The economic condition of forges in Normandy in 1811. G. Richard. (Rev. Hist. Min. Mét., 1969, 1, (2), 151-232) [In Fr.] In 1811, the French Ministry of the Interior carried out an investigation of the iron-making industries to examine the effect of the industrial crisis of that year. The interrogation reports on three districts of Normandy have survived; they show declines in production of varying degress of severity since 1789, although the Continental System had given them considerable shelter in 1802-1810, and production had increased during that period; it is concluded that this protection had been the downfall of the ironmasters, leading them to neglect technical improvements, such as the use of coke and of the puddling process. Even after the fall of the Empire they were still protected by customs barriers, and the Industrial Revolution was a long time coming. The paper concludes with 66 pages of very detailed questioning of 15 ironmasters in Eure, Orne, and Eure-et-Loire, in 1811-1812.

The recovery of Le Creusot, 1836-1848, J. B. Silly. (Rev. Hist. Min. Mét., 1969, 1, (2), 233-278) [In Fr.] When Le Creusot went bankrupt in 1833, the assets were brought by a consortium of creditors, with some of whom the banking family of Seillère soon formed an arrangement to restart the works. The brothers Adolphe and Eugène Scheider had a part in this arrangement, and technical control passed to the former. There were several years of technical development and diversification of production, notably into machine building and locomotive construction, before the concern reached its full stature as primarily concerned with heavy iron and steel work for the engineering industries and, very notably, for railway companies, in which it had considerable holdings. The Seillère bank advanced much money during these operations, but at the end of them the Schneiders and their associates were the majority shareholders, and the company was among the leaders of the industry.

The accounts of a Luxemburg metallurgical enterprise in the 18th century. G. Hansotte. (Rev. Hist. Min. Mét., 1970, 2, 21-48). [In Fr.]. An analysis of the accounts of the furnaces of Montauban and the forges of Prelle and Sainte-Ode from 1766 to 1784.

Note on the slags from the Carvelhelhos hill fort. H. Maia e Costa. (Trab. Antrop. Etnol. Soc. Portug., 1965-1966, 173-180). Petrographic examination and chemical analysis of a tin slag from an EIA hill fort in the north of Portugal. The slag contained about 2% metallic tin in the form of spheroids; the matrix was of the fayalite-type normal for iron and copper slags of the same period. [In Port.]

Contribution to the history of ferrous metallurgy in the region around Hunedoara, Romania. II. N. Chindler and S. Popa. (Metalurgia, 1969, 21, Sept., (9), 480-483) [In Rom.] An outline listing forges, smithies, and furnaces, mainly of the 17th-19th centuries.

Metallurgy in Andalusia, an historical review. R. Fuentes Guerra. (Dyna, 1969, 44, Apr, 137-147,) [In Sp.] The history of the development of metallurgy in Andalusia is reviewed, including some reference to modern developments.

Unpublished documents on the first blast-furnace at Klus (Soleure). P. L. Pelet. (Rev. Hist. Min. Mét., 1969, 1, (2), 129-150) [In Fr.] The economic and political reasons for the setting up of this establishment in Switzerland with French and Swiss capital during the Napoleonic wars, in 1810-1813, are given. A long detailed description by Benjamin Dellient, a Swiss technician, follows: the furnace, though solidly built, seemed low by the technology of the time. The shaft was only 18 in, the throat 2 ft 6 in, and the bosh 7 ft. The hearth was 16 in wide at the bottom. Dellient considered the bellows, driven by a rather small waterwheel, to be themselves too small, and working too fast for a reasonable life. He also considered the furnace to be badly run, not because the technical management was incompetent, but for other reasons he would put in a report which has not survived. The whole plant was spaciously and solidly built and the enterprise extravagantly run; with changes in economic and political circumstances, bankruptcy was very near in 1815 and was only avoided by financial sacrifice and perseverance.

Africa

Development of smelting and casting in Egypt between 2500 and 1500 BC based on sculpture and paintings. U. Zwicker. (Metall, 1969, 23, (1), 1-4). [In Ger.]. A short discussion of the technical processes used.

America

Jamaican castings, old and new. J. Blakiston. (Foundry Trade J., 1970, 128, 14, May, 831-833) Examples of the historic iron castings described are the Rio Cobre bridge, early iron cannon and the cannon look-out, the Fort Charles stone and cast-iron building, and cast-iron water-wheels. The restoration of a water-wheel by the Kingston Industrial Works Ltd is mentioned.

Early Pennsylvania ironmaking: fascinating forerunner of world's largest iron and steel industry. Anon. (Foote Prints, 1970, 38, 1, 2-12). A popular account in the house journal of the Foote Mineral Company of the origins of the iron industry in Pennsylvania, with descriptions of the restored ironworks at Cornwall and Hopewell Village, Pa. Good descriptions of charcoal manufacture and the early blast furnace process.

Asia

An archaeological survey of South Sinai, 1967-68. Beno Rothenberg. (P. E. Q., 1970, Jan-June, 1-29). This is a preliminary report of the first (1967-68) season, and a report on the metallurgical conclusions will follow. Evidence was found of Chalcolithic copper smelting, and it is thought that this area acted as a bridge between Egypt and Asia in Chalcolithic times. This paper does a lot to clear up problems raised by Petrie's work ('Researches in Sinai', 1906).
Rothenberg found evidence of numerous expeditions in SW Sinai from the beginning of the Old Kingdom well into the New Kingdom. In both Wadi Maghareh and Serabit el-Khadem only turquoise was mined. This renewed an ancient Chalcolithic tradition.
He did, however, find a copper mining and smelting installation at Bir Nasb, 30 km from the Gulf of Suez, where a large slag heap (110 × 200 m, 2-3 m high) was found, as reported by Petrie on p. 27. Petrie had found a copper ingot on this site which contained 5.9% Fe, 1.0% S and 0.08% As according to Desch (1st report to the B.A.). This site was dated to the 18-15th century BC by Rothenberg. The copper was difficult to exploit and the output was not large. The heyday of the site was much later in the Nabatean-Roman-Byzantine period, which used the large mine at Jebel Umm Rinna. Fuel was available at Bir Nasb.

The conclusions are that Sinai was primarily a source of torquoise and not copper. The area was abandoned between the Chalcolithic and the Nabatean-Roman-Byzantine period.

The extractive metallurgy of the Early Iron Age copper industry in the 'Arabah, Israel. A. Lupu and B. Rothenberg. (Arch. Austriaca, 1970, 47, 91-103). This paper enlarges on certain aspects of the earlier paper on this subject in JIM, 1967, 95, 235-243. It contains additional information, including the microstructure of slags and copper pellets and also some very interesting photos of sites and artifacts. Comparison is made of the composition of the slags found with those from modern copper smelters.

Australia

Tamar Valley ironmaking. Anon. (BHP Rev., 1969, 45, Spring, (7) 29-32) An historical account is given of the 100-year-old iron industry in northern Tasmania.

Mining

Considerations on the antiquity of mining in the Iberian peninsula. J. C. Allan. (Royal Anthrop. Inst. Occ. Paper No. 27, 1970, 30s/£1.50) This an extended version of the paper published in the HMG Bulletin, 1968, 2(1), 47-50. This work covers gold, silver, copper, and tin. The slag compositions are compared with those from similar sites in Cyprus and elsewhere.

He adds a useful note on the consumption of charcoal: 90 kg of wood was required for every kg of copper. One acre would produce 93 tons of wood in 43 years, and therefore one metric ton of copper would consume 20 square miles of woodland on a 40 yr rotation. This would put a definite limit to tonnage that could be produced at any period. At this rate, the 15 million tons of silver slag would have taken 1 000 years to produce.

Problems of mining technique in the Middle Ages. B. Gille (Rev. Hist. Min. Mét 1969, 1, (2), 279-296) [In Fr.] There are other documentary sources than Agricola's 'De Re Metallica' for the understanding of the mining technique of the Middle Ages. Mining regulations (of which the author quotes 26 publications), illustrations (of which some come from the 15th and 16th centuries), and actual excavations. The last are less easy to interpret if there have been pre- and post-mediaeval workings, but names exist which it is known were abandoned in the 12th century, i.e. at the time of the Great Plague, and in some cases, there is architectural evidence. By such studies and comparisons, shaftsinking (with and without lining), man-ways, working places, hoists, airways, lighting methods, tools, haulage, and drainage can be identified, and the beginnings of application of mechanical power. Much, however, remains obscure, and the study of written sources, especially mining regulations, linguistic studies, and actual excavation of mediaeval sites, will help to make it more concrete.

Geological background to ironstone mining in Cleveland. J. Owen. (Trans. Teesside Indust. Archeol. Group., 1969, 1, pp. 8) The various ironstone seams in the Cleveland, Rosedale, Farndale, and Murk Esk Valley region of the North East Coast are described and a section of the seams showing the extent and depth of the ironstone is illustrated. A great many ironstone seams exist in the Cleveland district, but only six have attracted the interest of industrialists since the first quarter of the 19th century. These include such companies as Cargo Fleet Iron, Skinningrove Iron Co., Bell Bros. Ltd. etc.

Slags

Investigation of slag specimens from Muhlthal. M. Bartuška and R. Pleiner. (Münchner Beitrage Vor-u. Frühgeschichte. 1968, 13, 99-101, +4 pp. ills. reprint). [In Ger.] Analyses of ironmaking slag are discussed. It is concluded that the specimens found in pits antedating 8th cent. AD probably arose from a smithy and not from local ironmaking.

Classification of the structure of inclusions in slags and its application in determining the origins of ancient iron objects. J. Piaskowski. (Kwartal. Hist. Kult. Mat., 1969, 17, (1), 61-71). [in Pol.] The preliminary classification system proposed by the author in 1963 has been improved after further work and discussion. A typology based on statistical and analytical evidence is presented for slags found in Poland, which are classified into five main divisions.

Techniques

Archaeological classification by metal analysis. E. A. Slater and J. A. Charles. (Antiquity, 1970, 44, 207-213). The authors have studied the segregation of Bi in laboratory copies of socketed axes made in clay moulds with graphite cores. The composition of the copies was in the range 6.6-8.8% Sn, 0.0088-0.16% Bi, and 0-6.1% Pb. They conclude that the variation of composition in different parts of the axe due to segregation is of no importance in relation to analyses performed for most archaeological purposes, but is of significance when the object is to be classified on the basis of trace elements. This is particularly relevant to the work being carried on by the Stuttgart team, where there is a classification division at 0.08% Bi. Differences due to segregation are such that if only a single drilling has been taken its position could affect the group into which the object was put, and hence its possible provenance.

The segregation of lead is much as Coghlan found it in 1953 (Man, 53, 97-101), i.e. not as much as one would expect. The maximum range in this work was from 5.88% to 6.02%, which was not significant, since the analytical method error was assessed at 4%. Work is continuing on the effect of other elements.

Technique of fabrication and research into the provenance of copper artefacts of the Remedello culture. L. Matteoli and C. Storti. (Inst. Lombardo (Rend. Lett.) Rendiconti, 1967, 101, 661-680). [In Ital.] Quantitative spectrographic analyses and the microstructure of six artifacts of the Remedello culture, which had previously been chemically analysed by Otto and Witter, gave an estimation of the trace elements. None contained tin, and the arsenic content varied from a trace to 7.8%. One contained visible slag but the iron was low in all cases. Na, Ca, and P were often detected and probably came from the fuel.

A dagger from a tomb at Remedello was badly corroded but showed slip bands and twins. A microscan showed a central metallic zone containing 4.65-26.5% As, 0.68% Cu_2O, with 73 to 96% Cu. A flat axe showed primary and eutectic cuprous oxide; there was evidence of some plastic deformation followed by annealing.

It was concluded that the compositions were typical of Fahlerz with As, Ni, Ag, and Bi present and Sn, Au, Co, and Zn spectrographically absent. A definite provenance for the ore could not be established, but Montemerano was possible.

Observations on the natural patination of copper. M. Schmidt. (JIM, 1970, 98, 238). Neither the type of copper nor its hardness determine the rate of natural patination in the atmosphere, but the total time of exposure to corrosive water.

The tinning of objects of copper and bronze in early times. A. Thouvenin. (Rev. Hist. Min. Mét., 1970, 2, 101-109). [In Fr.] On the basis of the 18th century description of the making of brass pins in Diderot, and other data, it is concluded that early tinning was sometimes done by dipping the object in a boiling aqueous solution of argol (potassium bitratrate) containing granules or thin leaves of tin. In the 19th century, Roret's encyclopedia recommended a solution of cream of tartar and tin chloride. The leaves of tin, which were about 0.5 mm thick, lasted from a week to three months. This technique is electrochemical and deposits a very thin layer of tin on the work, which means that there is no tendency to fill a carefully engraved design such as that on Merovingian jewellery.

Research on the plating of ancient coins with the help of electron microanalysis. E. Kalsch and U. Zwicker. (Mikrochimica Acta, 1968, Suppl. III, 210-220). [In Ger.] The authors show that silver-plated coins made between the 5th and the 1st centuries BC were probably made without the use of a solder. However, liquid intermediate layers have formed owing to overheating during plating. After the beginning of the Christian era, and particularly in the Sassanian period in Persia (6-7th centuries AD), the use of a copper-silver alloy solder was probable.

Some experiments in Greek minting technique. D. G. Sellwood. (Num. Chron., 1963, 3, 217-231). The production of silver coins using 20% tin-bronze dies. The latter were made from sand castings 4 in long and 1⅜ dia, cut into 1 in long slices. Similar bars were die-cast in steel moulds and water-quenched from 650°C to soften. The design was cut into the latter by hubbing, i.e. by first forming a punch with the design in relief as it would be on the actual coin. This was done with a small steel chisel and a few files. After, the bronze was hardened by reheating and slow cooling.

One of the sand-cast slices was then heated to 720°C and, after placing it on an anvil, the hub was driven into it. Four blows and one annealing were enough to get a sufficient depth of design into the lower die or pile. For the upper die or trussel, three more bronze bars were cast into the steel mould. One of these was then engraved with steel tools. This die was used direct with hubbing.

99.5% fine silver was used for the blanks, which were cast by pouring from a crucible into circular depressions in a cast-iron plate. It was found that 17 g nominal-weight blanks could be cast with a tolerance of ±0.5 g six out of eleven times. These blanks were hot-struck at a temperature of 700°C with two blows of a 2.5 lb hammer at the rate of 100 coins per hour. After about 30 coins, the top of the trussel began to crack and had to be reinforced with a steel ring. With modifications, the trussel made 7786 while the pile made 9404 coins.

Metallographic Examination

Researches on iron bars from the Renningen hoard. U. Zwicker. (Fundberichte aus Schwaben, (N.S.) 1967, 18(1), 282-283). [In Ger.] A microstructural examination of a spindle-shaped bloom. The bar was 49 cm long and weighed about 4 kg. It was a partly smithed bloom with between 0.1 and 0.5% P, probably made from the south German Dogger ores. It was very inhomogeneous with carbon varying from 0.05% (with high % P) to about 0.7% with low P. There is a marked 'parting line' across the middle and the ends show marked flow lines. A micro-tensile test gave a strength of 57 kp/mm².

Metallographic examination of ancient iron objects from the province of Lodz. J. Piaskowski. (Stud. Dziejow Gorn. Hutn., 1967, 12, 7-27) [In Pol.] Analyses and tests are described for 24 iron objects which are dated from 1st century BC to the 4th century AD. The objects were divided into four types based on chemical contents. They include a pattern-welded sword believed to be of Roman origin, probably brought to the area by a military expedition.

Further metallographic examination of iron objects from Igolomia, Poland. J. Piaskowski. (Wiadomosci Archeol., 1966-7, 22, (2-4), 465-479) [In Pol.] Analyses and tests are described for 25 objects (six dating from 3rd-4th centuries AD and three from the early Middle Ages, the rest of unknown chronology) found in the Pioszowice district of Poland.

Metallographic investigation of knife blades from an early Slavonic settlement in Dessau-Mosigkau. B. Krüger, R. Pleiner, H. H. Müller, C. Müller, and K. D. Jäger. (Deutsche Akad-Wiss. Berlin Schrift. Vor-u. Frühgeschichte, 1967, 22, 175-90 + 12 pp. ills). [In Ger.] Analyses and the presumed technology are described for iron objects from an early Slavonic (second half of the 6th century to the beginning of the 8th century AD) metalworking site in the central Elbe region.

Metallographic examination of iron objects and slag fragments from Szeligi and Cekanowo (Plock district) and Cieslin (Sierp district). J. Piaskowski. (in W. Szymanski, 'Szeligi pod Plockiem,' Warsaw, 1967, pp 363-397) [In Pol.] Analyses are described of iron objects found on the site of a fortified Slavonic village (6th-8th centuries AD). The atuhor, basing his hypothesis on slag fragments, suggests a local origin.

Further metallographic studies on ancient iron objects from the Kielce region. J. Piaskowski. (Rocznik Muz. Swietokrzyskiego, 1968, 5, 151-198 [In Pol.] Descriptions and analyses are given of artefacts from the Swietokrzyske (Holy Cross) Mountains iron-making region, mainly drawn from the Museum in Kielce, Poland.

Book Notices

J. Cambell, D. Elkington, P. Fowler and L. Grinsell:
The Mendip Hills in Prehistoric and Roman Times (Bristol Archaeological Research Group, City Museum, Bristol, 1970, 5/- 36 pp.)

The section on the Roman period contains a short account of Roman lead working in the Mendips.

H. H. Coghlan and G. Parker:
Metallographic research as a museum aid; an examination of two pure copper flat axes (Newbury, The Museum, 1969).
H. H. Coghlan:
British and Irish Bronze Age implements in the Borough of Newbury Museum (Newbury, 1970: available from the Museum, price 10/-).

A metallographic examination and chemical analysis of 32 flat, flanged, and socketed axes and palstaves. One of the flat axes contained 2.2% Zn and one of the palstaves 8.6% Zn. Not all the socketed axes were leaded although many of them had a local provenance. A Hungarian axe-hammer was also examined.

R. F. Tylecote.

H. H. Coghlan and G. Parker:
A report on the hoard of Bronze Age tools and weapons from Yattendon, near Newbury, Berks. (Newbury Museum, 1970. 10/-).

An analytical and metallurgical report on a founder's hoard containing material from the Early to the Late Bronze Age. This is fully illustrated with photomicrographs of many of the implements together with hardness tests. The tin content of the majority falls in the range 5.6-15.1% and the lead content of the typologically late objects is high. Two objects contain 3.3% and 1.8% Zn respectively. Whilst this is unusual, it is not unexpected considering the zinc content of some of the Irish and British ores. This is a very complete, useful, and interesting treatment of an untypical hoard, and an example of what needs doing on a much wider scale.

R. F. Tylecote.

Ya. I. Sunchungashev:
Mining and smelting of metals in Ancient Tuva [in Russian] (Moscow, 1969)

The ASSR of Tuva lies to the north of Mongolia between Lakes Baikal and Balkash. It consists almost entirely of the upper reaches of the river Yenesei and lies on the steppe corridor between the tundra and the desert, a route that is of importance to early man and the diffusion of ideas and peoples. This is the area of the Afanasevskaya and Andronovo cultures discussed by Minns and Mongait.

Details are given of the mining site at Kory-Aks and the stone and antler tools used, the former bearing a striking resemblance to those from Alderley Edge, Cheshire. The oxide ores were found to contain 6-10% Cu and 0.11% As.

Typologically, the artifacts are of Early Bronze Age date and the moulds are of stone, which is unusual for such slender objects as knives and daggers. As would be expected, the analyses cover low-arsenic tin-bronzes and arsenical coppers; the contents vary from 0 to 9% Sn, 0 to over 10% As, and 0 to 0.2% Pb.

A copper-smelting furnace was found at On-Kashaa which was dated to the 7th to 6th century BC. Plans and sections are given. The slags have been fluxed with iron and contain 2-8% Cu. Again, pieces of stone mould were found but mainly for ornamental metalwork. Pieces of tuyere were found at Kizil Torg.

A number of the sites had been used for iron working. Magnetite, which occurs in the same deposits as the copper and which no doubt was used as flux, seems to have been the main iron ore used. Tuyeres were found with bores of about 30 mm and furnace complexes were excavated which contained the remains of shaft furnaces with side openings. The slags were of typical bloomery composition with low lime.

This is a most interesting report and a model of its kind. It would be well worth a full translation.

R. F. Tylecote.

E. N. Chernih:
History of the Earliest Metallurgy in Eastern Europe.
[In Russian]. (Moscow 1966, 143 pp)

This covers the area between the Dniester and the Urals, i.e. European Russia and the Caucasus. The treatment is rather like that of Otto and Witter. The book consists of analytical tables (containing 651 analyses) with outline drawings of some of the artifacts analysed. The results are compared by means of histograms and other statistical techniques; there is no attempt to create analytical groups and relate them to specific areas as in SAM I and II.

R. F. Tylecote.

L. Jeníček and Ivo Kruliš:
British inventions of the Industrial Revolution in the iron and steel industry on Czech territory [In English].
(National Technical Museum, Prague, 1967, 120 pp.)

This booklet was inspired by the late Professor Píšek. It shows the influence of British inventions on the iron industry of Bohemia, Moravia, and Silesia, which for muchof the period covered was the main industrial base of the Austro-Hungarian empire. At the beginning of the 19th century, production of iron per capita was remarkably high, considering that it was all made from charcoal. However, owing to this limitation, by 1865 it had only reached 10 kg per capita, which figure was reached in Britain in 1797 by the use of coke. In the Czech lands, with the aid of coke, it had increased to 20 kg per capita by 1875 and was raised from 20 to 30 kg in two years around 1883.

The first contact with Britain was over the question of blast furnace blowers. In 1801 a Czech visited Britain and this was followed by the Baildon family leasing a Czech furnace and successfully obtaining a cast-iron steam-engine cylinder locally. The authors assume that this led to the successful production of precision blowing engine cylinders. By 1828, the first coke-fuelled blast furnace was blown in at Vítkovice. Puddling was introduced in 1830 by three Welshmen, probably from Penydarren. Blast-furnace stoves of the Calder type were introduced at Ransko in 1836.

By 1843, Vítkovice had 26 English-type coke-ovens. The beehive ovens in the 1850's at Kladno were similar to those used in Newcastle upon Tyne in 1765 (Jars), but there were twelve in one block and the combustion gases heated a steam boiler.

British mechanical engineers had started making rolling mills near Prague in 1842, and there is evidence of continual interchange of experience between Britain and the Czech lands.

The significance of the Bessemer process was first seen by Tunner in Austria in 1863, but the Vítkovice works soon followed in 1866, using Slovak pig iron; the steel was rolled into rails. As elsewhere, the introduction was slow, owing to unsuitable ores, but when the Thomas process was invented progress was rapid, particularly in the Kladno area where the phosphorus content was high. The first experiments were made in 1879 and many pages are devoted to the sucessful adoption of this process.

At Vítkovice, with its lower-phosphorus ores, a duplex process was at first adopted, to be followed by other even more complex processes. Later, in 1902, the Talbot process replaced these processes.

After the foundation of the Czechoslovak state in 1918, more general influences prevailed in Czechoslovakia and French capital helped to re-equip the Skoda works, which became a nucleus of Cezch engineering and the source of many important contributions to the British iron and steel industry.

R. F. Tylecote.