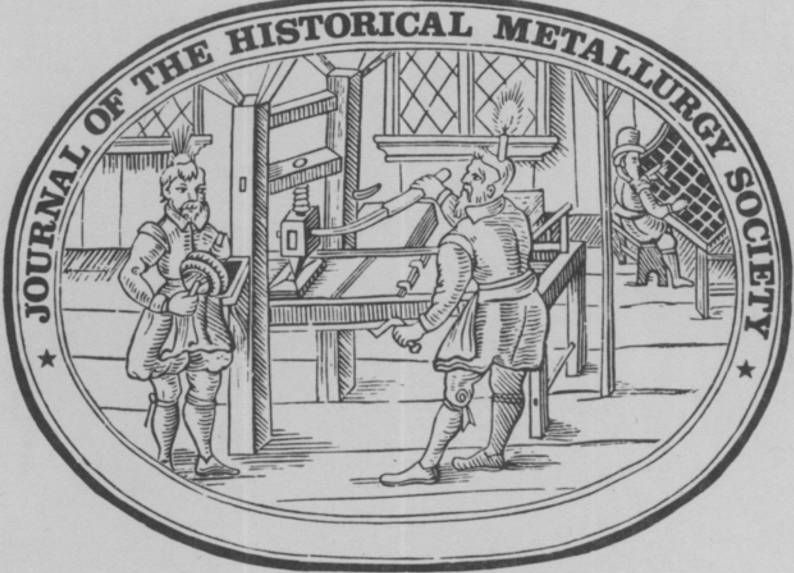
HISTORICAL METALLURGY

REPRINT EDITION



VOLUME 1 NUMBER 8 1967

The Historical Metallurgy Society has published the results of research into many aspects of the history of metals since 1963. As interest in the subject continues to increase, the Council decided, as a matter of principle, that it should ensure all publications of the HMS remain available for purchase in some form or other.

The very earliest regular publications were known as Bulletins. Of these numbers 1 to 6 (inclusive) covering the years 1963 to 1966, have been reprinted bound into one volume. Bulletins for the years 1967 to 1974 (fifteen issues in total) are available.

Since 1974 the Society's publications, produced twice each year, have been entitled *Historical Metallurgy,* the Journal of the Historical Metallurgy Society, and every endeavour has been made to maintain stocks of original editions. Since, however, this has not always been possible arrangements have now been made to produce facsimiles in the most economical manner whilst still preserving the essence of the original volumes.

This edition has been made possible with the ready co-operation of Alex den Ouden, of De Archaeologische Pers of Eindhoven, Nederland.

Since the *Journal* (formerly *Bulletin*) of the Historical Metallurgy Society began to be professionally printed in 1966 it has been customary to use a cover illustration with both historical and metallurgical connotations.

Usually there has been a deliberate link with an item appearing in that particular Volume, a policy which posed a problem when the Society decided to introduce Reprint Editions, which for technical reasons could not appear with the original cover illustrations.

However if the development of metal working is considered alongside the history of printing it is quite clear that Gutenberg owed a great deal to the art of the pewterer.

In Biringuccio's *Pirotechnica,* which was published in 1540 and is the first printed book on metallurgy, there is a description of type-founding which is in itself the earliest known record of the subject and so therefore it is quite appropriate to use a wood engraving of an early print-shop.

The illustration is from *De Sabbaticorum Annorum Periodis Digestio* published by R.Pont in 1619.

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Correspondence relating to the contents should be sent to the Honorary Editor: **Professor Ronald Tylecote,** Yew Tree House, East Hanney, near Wantage, Oxford OX12 0HT.

Enquiries concerning back copies of *Historical Metallurgy* and for details of other publications produced by the **HMS** should be made to **Roger Wood,** 99 High Lane West, West Hallam, Derbyshire DE7 6HQ who can also supply details of Society membership.

Designed and produced by Roy Day FSIAD and IBM Composer set by Kathleen Taylor.

Bulletin of the Historical Metallurgy Group

Early steelmaking. Agricola Book IX

volume 1
number 8
1967

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Report of the

SECOND ANNUAL CONFERENCE

Sheffield, 9-11 September 1966

The Second Annual Conference of the Group was held during the weekend of 9 to 11 September 1966. It was based on Sorby Hall, one of the halls of residence of the University of Sheffield.

There was a varied programme of papers at the discussion sessions. With the exception of Dr. R.F. Tylecote's report on his study of early copper in Israel, all the papers were of specifically local interest. Summaries of all the papers except that by Dr Tylecote appear in this issue of the Bulletin.

On the first evening there were two papers. Dr R.A. Mott discussed lead smelting in Derbyshire, a subject to which he has devoted a great deal of study in recent years. He considered the history of the industry from the Roman period up to the present century, and reminded the meeting that lead production in the UK was the largest in the world up to the mid-nineteenth century.

This was followed by a lecture by the Honorary Secretary, Dr R.F. Tylecote, on early copper smelting in southern Israel, based on a visit that he had made to the south Negev earlier in the year. His lecture was profusely illustrated by a series of magnificent colour slides. It is good to know that a report of this very important study is to be published by the Journal of The Institute of Metals during 1967.

Proceedings began again on the morning of 10 September with a lecture by Mr D.W. Crossley of the Department of Economic History, University of Sheffield, on the results of his excavations at Rockley. This is the site of a 16th century bloomery which comprised an ore-roasting house, a bloom hearth, and a string hearth. Despite very disheartening weather conditions during the period of his excavations, Mr Crossley had been able to recover a great deal of information about the design and operation of this interesting works.

Next, Mr J.M. Bestall gave an account of the Abbeydale Works. This industrial hamlet was the subject of an appeal recently, and as a result it is being restored to its early state. Mr Bestall, who is a member of the Extra-Mural Department of the University of Sheffield, gave a very lucid picture of the historical background of Abbeydale Works, which was still in operation for the production of scythes until the 1930's.

Finally, Mr K.C. Barraclough of Firth-Brown Ltd, who earns his living by running a plant operating one of the newest steelmaking processes (vacuum remelting), described some of the background to the steelmaking processes which made Sheffield steel synonymous with high quality in the past. He dealt with the prehistory and early development of the cementation and crucible processes, and then went on to discuss their use in Sheffield from about 1662 onwards.

On the Saturday afternoon there was a tour of sites of historical interest in the Sheffield area. This began at Abbeydale, where Mr.Lewis, Director of the Sheffield City Museum, and Mr Vessey, a former crucible steelmaker, acted as guides. Members were greatly impressed by the restoration work that has been carried out. The buildings themselves have been extensively reroofed and some of them almost completely rebuilt. The crucible shop is in working order and the rest of the machinery is being progressively refurbished. One of the problems has been the identification of the original purpose of some of the buildings, which have undergone many vicissitudes since they were built.

This was followed by a visit to the Wortley Forge, which is in the care of the Sheffield Trades Historical Society. Here members saw a number of hammers and cranes that were still in use in the 19th century. Unlike Abbeydale, Wortley Forge has not benefited from recent appeals and a good deal still remains to be done.

From Wortley members went on to Rockley, where an early blast furnace is also preserved by the Sheffield Trades Historical Society. This has recently been cleaned up and fenced in, although a considerable amount of restoration and consolidation is still needed. The opportunity was taken at Rockley to visit the site of Mr Crossley's excavations. Finally, a short visit was paid to the Hoyle Street laboratories of the British Iron and Steel Research Association, where the only surviving cementation furnace in the Sheffield area has been preserved. This furnace was in operation by Daniel Doncaster and Co.Ltd until 1951.

Dinner at Sorby Hall was followed by informal discussions based on short contributions by members, including one by Mr W.K.V.Gale on village steelmaking in India and the puddling process. The evening ended with the showing of a number of short films on scythe forging (using water-driven tilt hammers), cementation, crucible steelmaking, and shovel manufacture in Ireland.

The Conference ended with lunch at Sorby Hall on Sunday, which followed a visit to the Magpie (lead) mine, near Bakewell. There was no opportunity to go underground, but members were able to inspect the surface buildings and the early workings made along the vein.

The unanimous verdict of the forty members who took part in the Second Annual Conference was that it was a great success; most of the credit for this success is due to the hard work of the local organizing committee under the chairmanship of Mr.K.C.Barraclough.

Lead smelting in Derbyshire

R.A. MOTT

Until the Napoleonic wars ended, Great Britain was the chief producer of lead in the world and Derbyshire the county where most lead was produced in Great Britain. The production of lead in Derbyshire was traced from the occupation by the Romans (and used for their bath houses), through the Anglo-Saxon period (when lead was used for roofing and guttering of abbeys and cathedrals and for shrouds in stone coffins) and the Danish occupation of northern England to the Norman Conquest, when there were eight lead mines named in Domesday Book for the shire. The surge in building abbeys accelerated production in the 13th century, foreign demand increased the export of lead from the Humber estuary, and the ancient rights of the lead miners were recognized in law. It was only in the 19th century, when the deeper veins in Derbyshire proved unproductive that the lead mines in Northumberland and Durham, and those near Alston in Cumberland became more important than those of Derbyshire, though production continued here in a few mines until the present century. Some of the old Derbyshire mines still operate but produce lump calcium fluoride (a flux for steelmaking) as well as a purer form, of small particle size, for making hydrofluoric acid.

Derbyshire lead ores were almost unique in having so small a silver content as to make its recovery not worthwhile. Until Elizabethan days the process of smelting was, therefore, a simple one in boles (bowl hearths) on the tops of bole-hills, usually nearly 1000 ft above O.D., though the peculiar topography of the country usually enabled a pack-horse route to follow a high contour until just below the summit. The fuel was wood and the low melting point of lead made such lead-smelting (primarily desulphurization of the lead ores, galena, PbS) the simplest of all metallurgical operations.

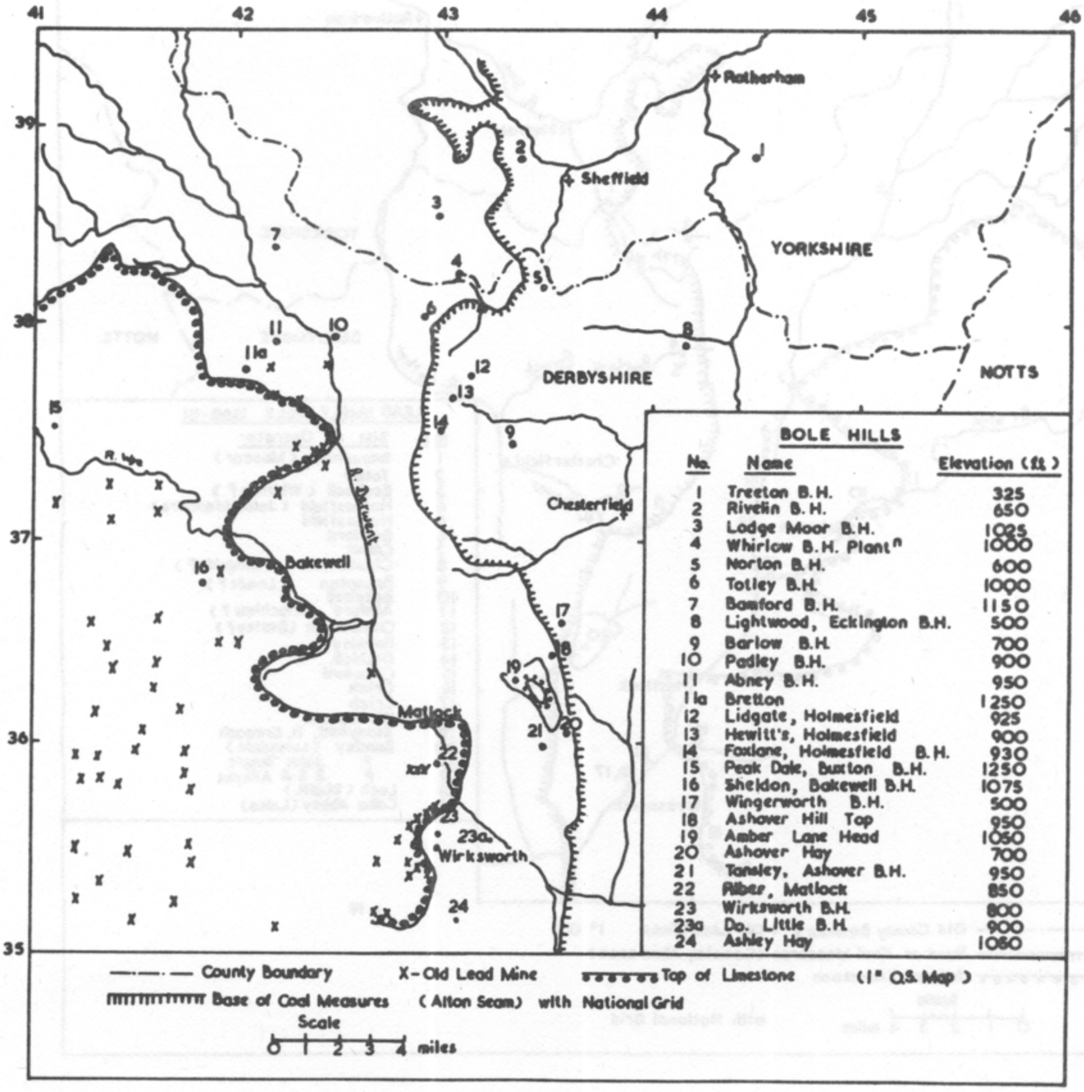

Fig.1 - "Bole hills" in Derbyshire

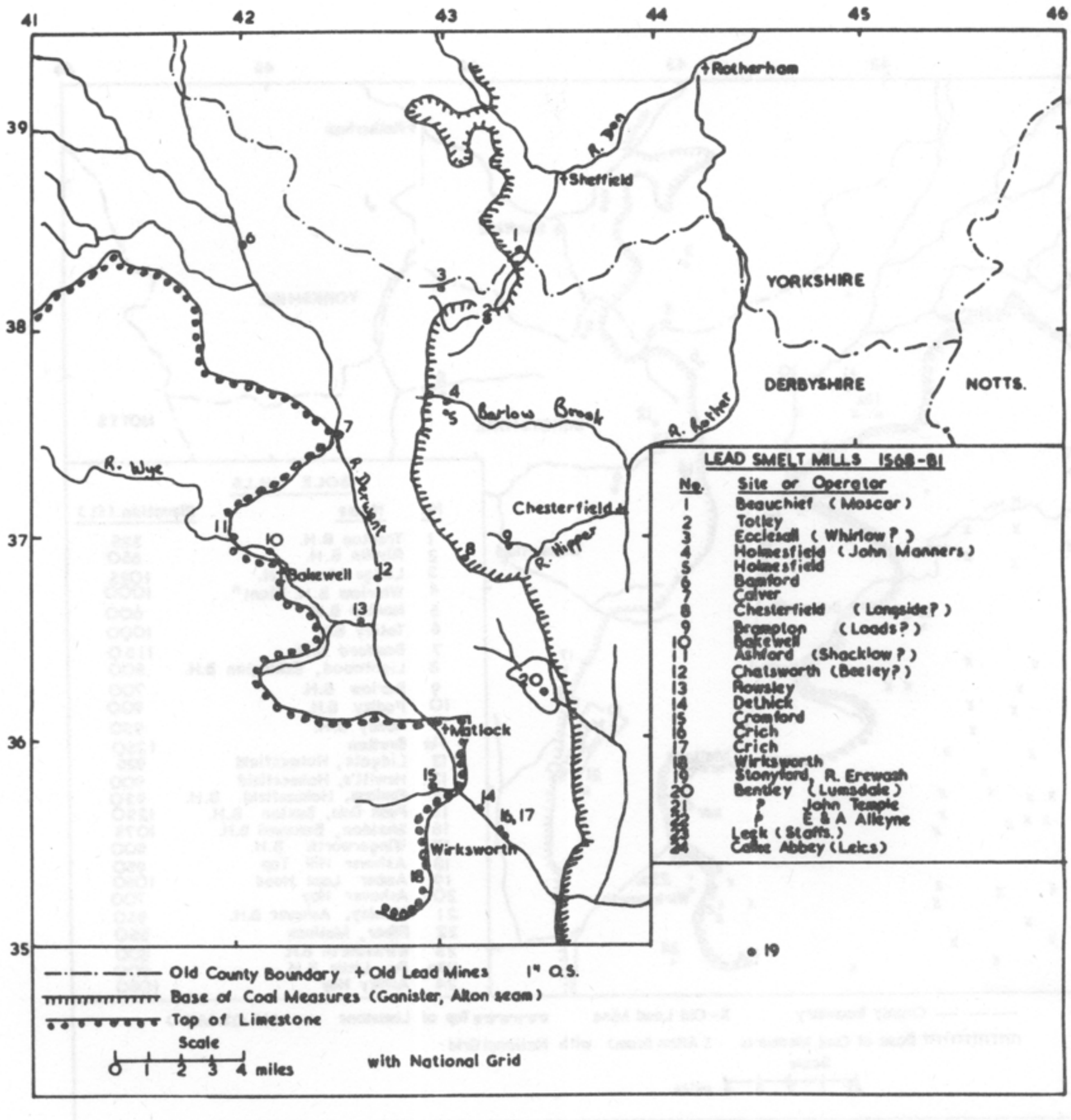

Fig.2 - Lead Smelt mills in Derbyshire, 1568-81

The lead ore was found in the limestone which prevailed to the west of the river Derwent. A map (Fig.1) of the sites marked on the O.S.maps or mentioned in wills shows the greatest concentration in the northern part of the county, just south of the older boundary of Yorkshire, and which was the ancient boundary between Mercia and Northumbria. This concentration may be attributed primarily to the fact that the old trade route ran due east from Sheffield to Bawtry, and thence along the river Idle to the Trent and the Humber estuary. A secondary factor was that wood was scarcer in the limestone area than in the heavy clay lands of the Coal Measures to the east.

In the period 1568-82 there was a remarkable change in smelting practice and the sites were moved from the hill-tops to the river valleys where waterwheels operated the bellows of "smelt-mills". The first of these mills was at "Beauchief" (which was identified as Moscar dam, now part of Sheffield) and the second at Totley, now also included in Sheffield. The first mill was built by William Humfrey who had, with the help of Sir William Cecil, formed the Society for Mineral and Battery Works and had acquired one of the first patents of monopoly of the Elizabethan period. The numerous imitators of Humfrey were the subjects of actions for infringement of monopoly in the Court of Exchequer. By 1641 there were 36 lead smelt mills in the townships of Dore, Totley, Holmesfield, and Walton and in the parishes of Brampton and Ashover in the northern hundred of Scarsdale.

In 1734 the first coal-fired natural-draught cupola for lead-smelting was built in Derbyshire and by 1750 another had been built at Totley, within sight of the second Derbyshire smelt-mill which was converted to a lead-rolling mill, the scrap from which was used on an adjacent site for making red lead. Usually a lead cupola had a slag mill to re-treat the slags from the cupola; such slag-mills were, in effect, the old smelt-mills, so that the cupolas tended to be built near them. Figure 2 shows the probable

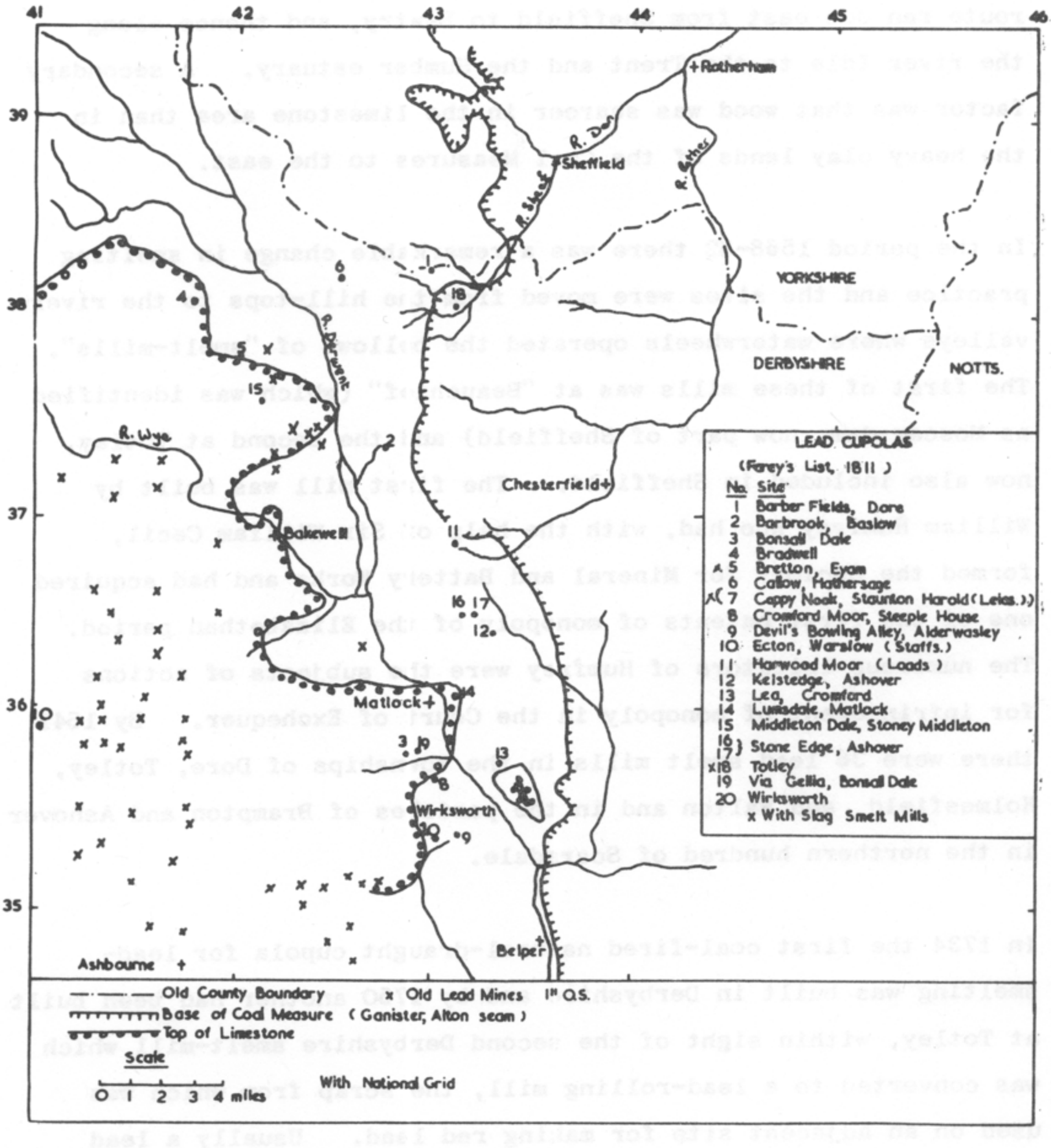

Fig.3 - Lead cupolas in Derbyshire (from Farey's list, 1811)

sites of lead smelt-mills in 1581 and Fig.3 the probable sites of Farey's list of lead cupolas of 1812. The lead cupola, or reverberatory furnace, was originally dome-shaped (hence "cupola"); since pig iron was also, until early in the nineteenth century, usually remelted in a similar furnace, the name cupola was passed on to the small coke-fired "blast" furnace which replaced it.

The bloomery at Rockley Smithies, Yorkshire

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Summary

Excavations have been carried out for three seasons at Rockley Smithies, and the site has proved to be a bloomery operated from the late 15th until the second quarter of the 17th century. Water-wheels were used to power bellows for three hearths, but the hammer was foot- or hand-operated. The site underwent a number of rebuildings, and evidence from structures and from pottery on the site dates these to the last fifty years of working. Firm evidence of bloomery operation and rebuilding into the 17th century prompts further examination of the chronology of the transition from bloomery to blast-furnace in England and the problems which accompanied it.

The route chosen in 1964 for the motorway from Sheffield to Leeds was found to threaten a group of derelict cottages known as Rockley Smithies (SE/340023), 6 miles south of Barnsley. The buildings were known to have housed an agricultural forge and colliery tramway workshop in the 19th century, but examination of nearby slag deposits suggested an earlier occupation. It was not at first clear whether this had been a bloomery, or a finery for the nearby 17th century blast furnace. The cottage foundations and the slags occupied a strip of raised ground stretching for about 300 yards along the south side of the Rockley brook. Trenches were dug at intervals along this strip, and an area of concentrated deposits was located.

The site was found to divide itself into two main areas, which may be conveniently dealt with chronologically.

(a) The early working floors. The north-west of the site was built up with layers and patches of bloomery cinder, charcoal, and ore-fines, and sandwiched between these were patches of burnt clay and vestigial building foundations; the area had been used for ore-roasting, and the burnt clay concentrations marked the centres of the fires. The bloomery slag had been dumped at intervals to maintain a level working area. Dating evidence was plentiful, beginning in the lowest layers with 15th century pottery, and continuing with a coin of 1504-7 and a series of pottery in the upper layers ending in the mid-16th century. The smelting hearths associated with this period on the site were not found.

(b) The main features of the eastern part of the site were grouped in an area excavated into the natural clay and cut through the eastern end of the roasting floor deposits. Three hearths were located in this hollow. At the northern end a Catalan bloomery hearth survived in good condition, built against a bank of natural clay revetted by the surviving stone shell of the hearth. The shell had fused with slag and was worn down on the side remote from the bank, although the gap through which slag had been tapped and the tuyere hole were recognisable. The reddened clay of the tap-slag depression was clearly visible. The second hearth was built on an ashlar plinth between a tailrace and the dam overflow and, having no provision for slag-tapping, would be used as a stringhearth. These two hearths lay on either side of a stone-lined tail-race covered in with stout timbers, which led water from a pair of overshot wheels, one for each hearth. The timber sleepers for the bloom-hearth bellows, with their surviving mortice holes, were in better condition than those adjacent to the string-hearth, which appeared only as stains on a floor of built-up slag and cinder. The wheelpits had undergone rebuilding; the earliest wheels had probably been installed in the second half of the 16th century, for no earlier pottery was found in this area. The north pit had a roughly-built breast, and could have accommodated a breast wheel over 3 ft in width. However, masonry

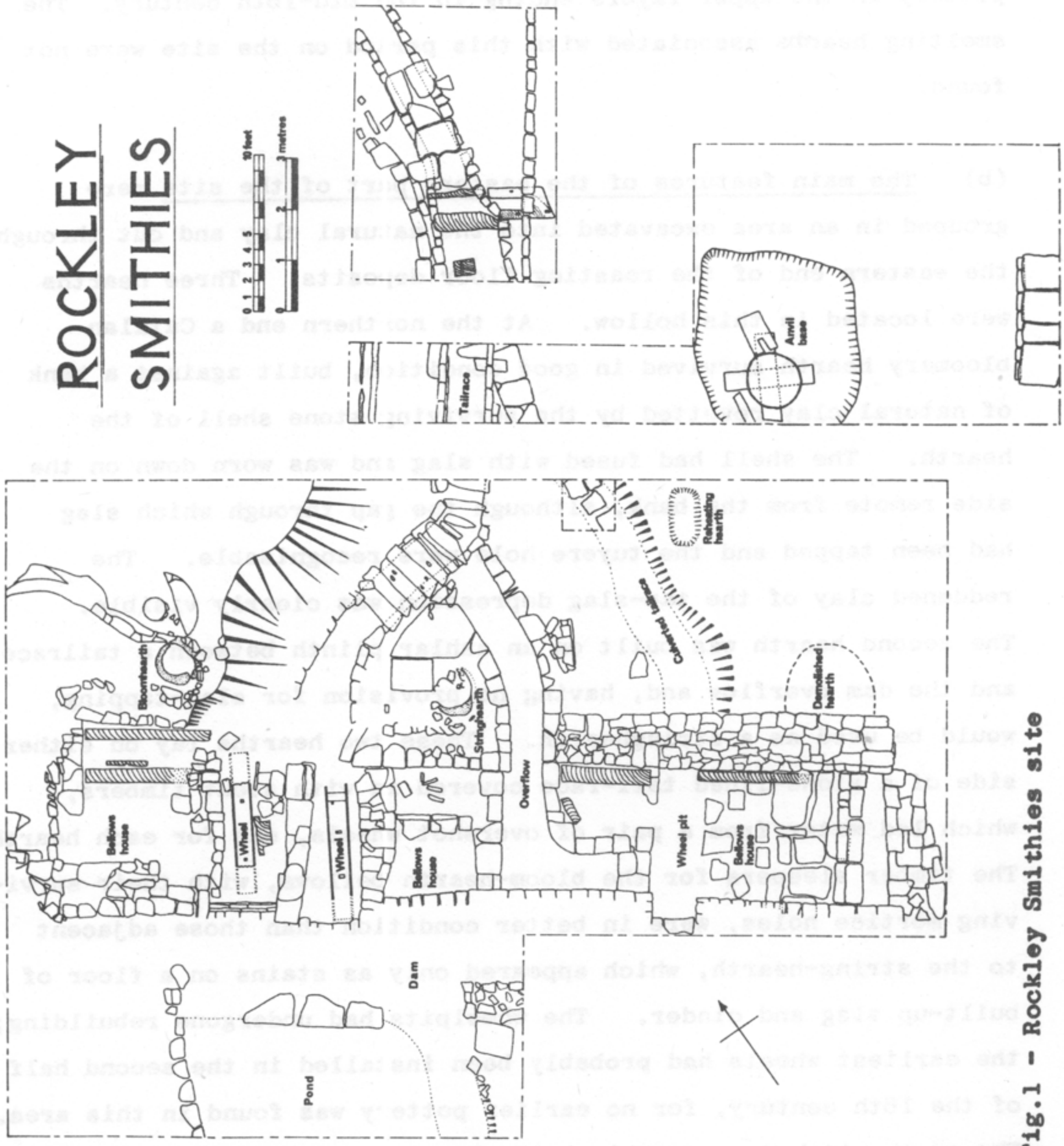

Fig.1 - Rockley Smithies site

had been used to narrow the pit, and the wheel whose lower part was formed in situ was overshot, 18 in wide and 10 ft diameter. This later wheel was left derelict for some seasons, as when the pit was finally paved over, it was not lifted out, but the remains were left in the pit bottom and covered with slag. The slag which surrounded the wheel is unlikely to have been dumped before the 1620's, the probable date of manufacture of pottery found in the deposit. The pit to the south had also been fitted with a new wheel, probably at the time of the final abandonment of the other pit. The wheel found in situ had run high in the pit, over a new floor of slag similar to that dumped around the north wheel. It appears that either a smaller wheel or raised bearings were used in the final phase, no earlier than the 1620's, and that the one wheel powered both hearths. The wheelpits lay at the foot of a clay and gravel dam, revetted with stone on the downstream side and whose effective height was increased by the excavation of the main working area. The pond was rather over an acre in size and was fed along a steep channel from a spring three-quarters of a mile away.

The area to the south of the stringhearth contained a wheel-pit from which the wheel had been removed. Adjacent lay a further hearth, of which little survived, and a stone support for bellows. The function of the hearth was not clear. The wheelpit had been abandoned before the rest of the site, for the outlet of its tailrace had been sealed off at its junction with the main channel. The penstock for this pit had been modified to produce a side-overflow, falling into a channel curving into a goit running immediately to the south of the stringhearth. Much of this channel had been inserted after the building of the stringhearth plinth, and it is likely that the original pond overflow was carried on a wooden trough to a point level with the plinth. After the abandonment of this southernmost wheelpit, the overflow had been converted again to a straight flow over the dam, falling into the same channel.

In the south-east corner of the site lay an anvil base formed of a section of tree trunk resting on a cruciform timber base. Although this had clearly received considerable force there was no possibility of water power having been used to operate the hammer. Two small reheating hearths without powered bellows lay adjacent to the anvil; one of these was sampled for dating by thermo-remanent magnetism.

The date for the closure of the works was indicated by the presence of pottery in the demolition layer covering the buildings and wheelpits dating from the middle of the 17th century and a reference in Royalist Composition Papers of 1643 to the derelict state of the iron smithies of the Rockley family.

It is appropriate to draw attention to the interval between the construction of the Wadsley Bridge and Kimberworth blast furnaces, before the mid-1580's, and the last use of bloomeries in the area shown by this site. Growth in the market for iron which encouraged landowners to abandon bloomeries and construct blast furnaces was slower in South Yorkshire than in the West Midlands and far behind the expansion in the South-East which fostered the transition in the Weald.

Abbeydale Works, Sheffield

J.M. BESTALL

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University of Sheffield

"A unique industrial hamlet of the eighteenth century, which represents technological history of great national importance" was the judgement of the Ancient Monuments Board on Abbeydale Works in its 1961 report. Here on the river Sheaf, 3½ miles south-west of the centre of Sheffield, is an exceptional group of industrial buildings of the late 18th and learly 19th centuries unified by the yard which they enclose. Their special interest is that together they represent all the processes involved in the manufacture of scythes and similar tools, and in addition include the warehouses, offices, and workmen's cottages which completed this industrial unit.

The two most important buildings are the Huntsman crucible steel furnace and the tilt hammer forge. The former contains six furnaces which have their distinctive chimney stack, the wooden floor where clay was brought to the correct consistency for the crucibles by treading with bare feet, and the shelves on which the crucibles were stacked. The latter houses the two tilt hammers and the blower for the hearths where the ingots could be reheated. In this forge the techniques used with water-powered machinery are impressively demonstrated. Crucible furnaces and tilt hammers have played such a conspicuous part in the industrial history of Sheffield that it is singularly fortunate that these last examples to survive in the city should be preserved together at Abbeydale. Also of considerable interest is the grinding shop with its four grindstones in their troughs, with provision for three smaller troughs, and its horizontal boring machines. The water-power for this grinding shop and the forge was supplied by two wheels, 18 ft in diameter, and two smaller wheels. When the water from the dam proved inadequate, a horizontal steam engine of about 1840, which stands outside the grinding shop, could be brought into action. At

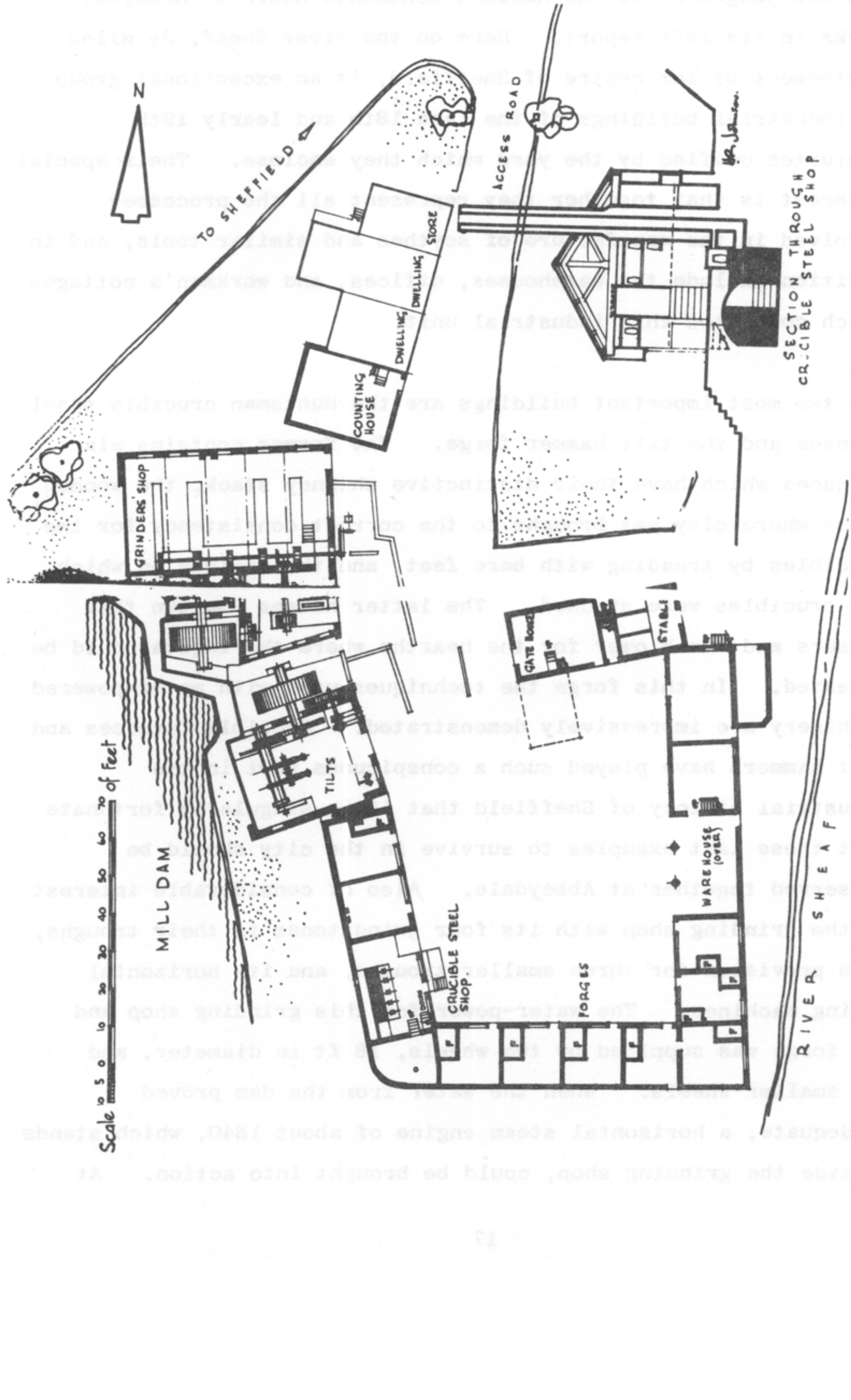
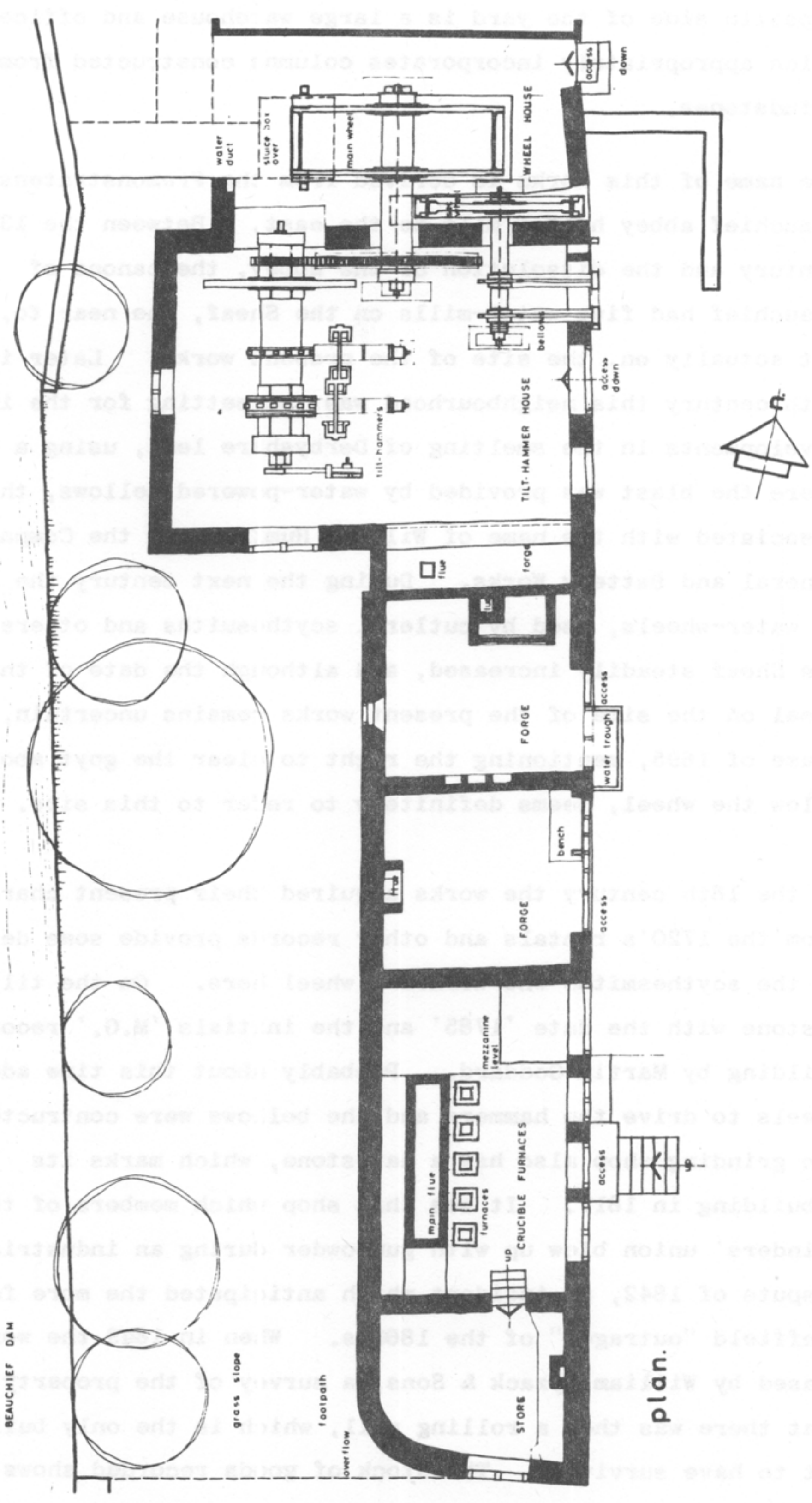


Fig.1 - General plan of Abbeydale Works

right-angles to these and subsidiary buildings is a row of six hand-forges for the use of individual craftsmen. On the opposite side of the yard is a large warehouse and office block, which appropriately incorporates columns constructed from used grindstones.

The name of this works is derived from the Premonstratensian Beauchief abbey half a mile to the east. Between the 13th century and the dissolution of the abbey, the canons of Beauchief had five water-mills on the Sheaf, one near to, if not actually on, the site of the present works. Later in the 16th century this neighbourhood was the setting for the important developments in the smelting of Derbyshire lead, using a furnace where the blast was provided by water-powered bellows, that are associated with the name of William Humfrey and the Company of Mineral and Battery Works. During the next century the number of water-wheels, used by cutlers, scythesmiths and others, on the Sheaf steadily increased, and although the date of the first wheel on the site of the present works remains uncertain, a lease of 1695, mentioning the right to clear the goyt above and below the wheel, seems definitely to refer to this site.

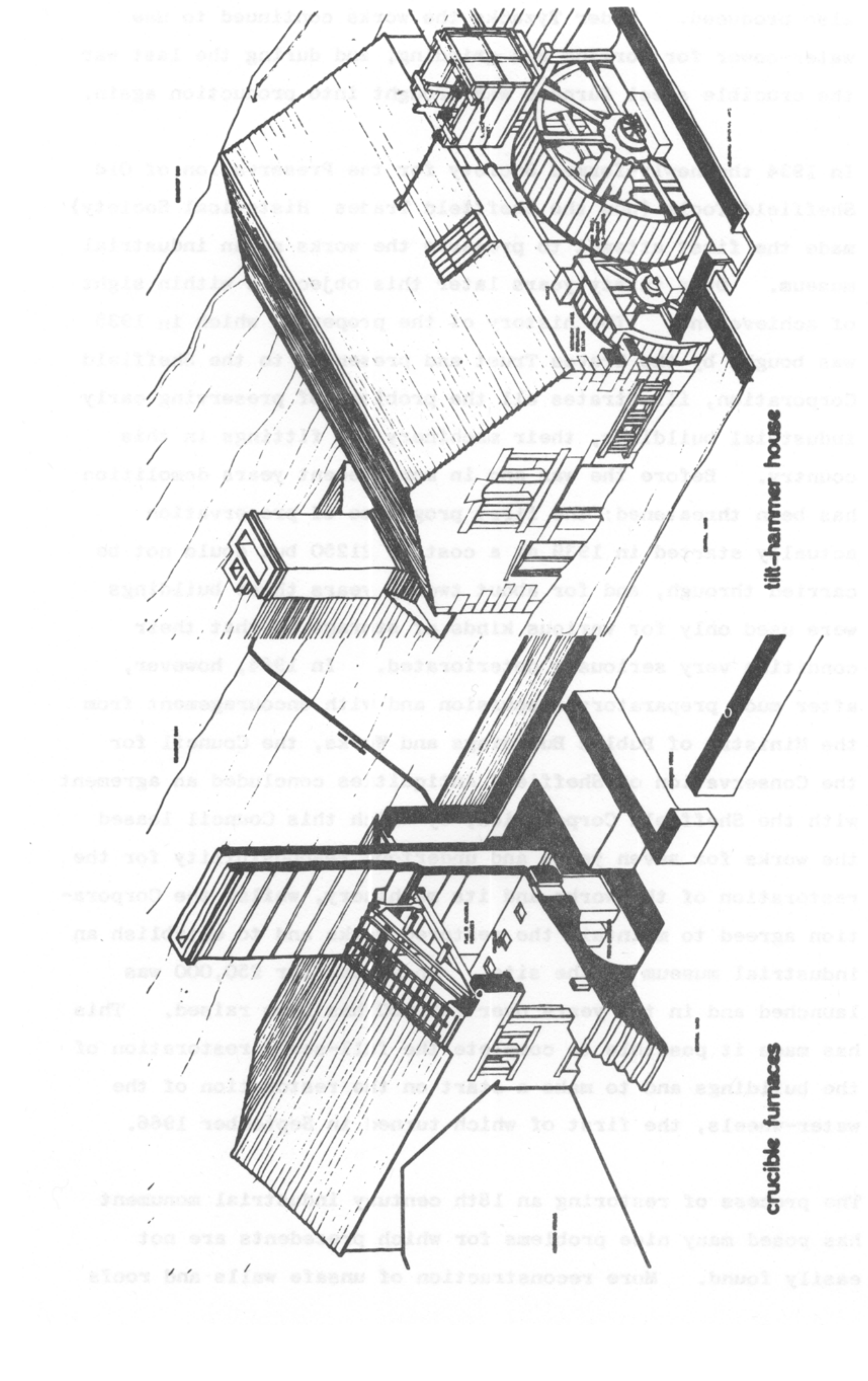
In the 18th century the works acquired their present character. From the 1720's rentals and other records provide some details of the scythesmiths who worked a wheel here. On the tilt forge a stone with the date '1785' and the initials 'M.G.' records its building by Martin Goddard. Probably about this time additional wheels to drive the hammers and the bellows were contructed. The grinding shop also has a datestone, which marks its rebuilding in 1817. It was this shop which members of the grinders' union blew up with gunpowder during an industrial dispute of 1842, an incident which anticipated the more famous Sheffield "outrages" of the 1860's. When in 1849 the works was leased by William Tyzack & Sons, a survey of the property showed that there was then a rolling mill, which is the only building not to have survived. The stock of goods recorded shows that


BEAUCHIEF DAM
grass slope
footpath
overflow
STORE
plan.
up
CRUCIBLE FURNACES
furnaces
main flue
access
mezzanine level
FORGE
access
bench
water trough
FORGE
access
forge
flue
TILT-HAMMER HOUSE
tilt-hammers
access down
bellows
WHEEL HOUSE
main wheel
sluice box over
water duct
access down

the works was then primarily engaged in the making of scythes, as it was until its closing in the 1920's, but sickles, hay knives, turnip knives, and a variety of other edge tools were also produced. Under Tyzacks the works continued to use water-power for forging and grinding, and during the last war the crucible steel furnace was brought into production again.

In 1934 the newly-formed Society for the Preservation of Old Sheffield Tools (now the Sheffield Trades Historical Society) made the first attempt to preserve the works as an industrial museum. Over thirty years later this object is within sight of achievement. The history of the property, which in 1935 was bought by the Graves Trust and presented to the Sheffield Corporation, illustrates all the problems of preserving early industrial buildings, their machinery and fittings in this country. Before the war and in more recent years demolition has been threatened: the first programme of preservation actually started in 1939 at a cost of £1250 but could not be carried through, and for about twenty years these buildings were used only for various kinds of storage so that their condition very seriously deteriorated. In 1964, however, after much preparatory discussion and with encouragement from the Ministry of Public Buildings and Works, the Council for the Conservation of Sheffield Antiquities concluded an agrement with the Sheffield Corporation, by which this Council leased the works for seven years and undertook responsibility for the restoration of the works and its machinery, whilst the Corporation agreed to maintain the restored works and to establish an industrial museum on the site. An appeal for £50,000 was launched and in two years over £42,000 has been raised. This has made it possible to complete the full-scale restoration of the buildings and to make a start on the restoration of the water-wheels, the first of which turned in September 1966.

The process of restoring an 18th century industrial monument has posed many nice problems for which precedents are not easily found. More reconstruction of unsafe walls and roofs


tilt-hammer house
crucible furnaces

had, for example, to be undertaken than originally envisaged. Modern techniques of preservation have been combined as tactfully as possible with the use of old materials. Now a custodian resides in one of the workmen's cottages, the interior of which has been refashioned to modern housing standards, and preparations are advancing for the eventual opening of the industrial museum at Abbeydale Works which it is thought will have no equivalent in this country.

The cementation and crucible steelmaking processes

K.C. BARRACLOUGH
Firth-Brown Ltd.
Sheffield

Cementation

The cementation process represents the first positive attempt to produce steel in a relatively reproducible and large-scale manner. Bars of wrought iron, roughly 3in x ¾in section, packed in charcoal in sandstone chests and sealed with a cement made from wheelswarf, were heated in beehive-type furnaces to temperatures of the order of 1000-1100°C for periods of 10 to 14 days and withdrawn after cooling in situ for a further 7 to 10 days. The bars so produced were "blister steel", the blisters on the surface being caused by the reaction of the carbon absorbed into the steel with the entrained slag present in the raw material.

The bars of blister steel were fractured and the grade or temper established by the assessment of the appearance of the fracture. In Temper 1, for instance, there was a fine crystalline layer just below the skin on each side of the bar, but the centre portion retained the fibrous character of the wrought iron. In Temper 4, the three layers were about even in thickness; Temper 5 showed fine crystals all through the section; Temper 6 showed coarse crystals all through, whilst Temper 7 showed very coarse crystals with bright facets throughout. The usual designations of these tempers, together with the average contents of carbon through the section, were:

No.1	0.5%C	Spring heat
No.2	0.65%C	Cutlery heat
No.3	0.8% C	Single shear heat
No.4	1.0% C	Double shear heat
No.5	1.25%C	Steel through heat
No.6	1.5% C	Melting heat
No.7	1.8% C	Glazed heat

Obviously time and temperature during cementation were controlled to give roughly the required temper. Nos.6 and 7 were, incidentally, not made intentionally before Huntsman's time; they were not forgeable and were only made specially later for remelting in the crucible process. Tempers 1 to 5 could, however, be forged; they were often forged by reheating single bars and tilting them down to a size which could subsequently be rolled in a small mill. The classic procedure, however, was to break the bars into lengths of around 18in, to bind six or eight such pieces into a "faggot" with an iron hoop, to coat the faggot in sand or borax, and to heat it to a good forging temperature. The faggot was then forge welded into one bloom and forged down to a single bar of around 2in x ¾". This was the famous "shear steel" (or, to be more precise, single shear steel) from which knife blades and other cutting edges were made. This process greatly increased the homogeneity of the blister steel.

To get even better results, the single shear bar was broken up into lengths and again faggotted, welded, and forged, to produce "double shear steel", which produced better cutting knives than we are ever likely to see again, now we put such a store on stainless cutlery. Some carbon was lost each time the faggotting and forging was carried out; thus Temper 4 converted to double shear and Temper 3 converted to single shear gave approximately the same carbon as Temper 2 forged direct, hence the names given to the various tempers.

The cementation process possibly dates back to 1556 in Italy or to 1613 in Holland. Certainly in 1682 it was operated in Newcastle and in 1709 in Sheffield. One important fact that certainly explains its early location in Newcastle is that the only raw material found to give a satisfactory product was charcoal wrought iron from Sweden. It is also an interesting commentary that in 1800 there were 93 converting furnaces in Sweden, but there were only 56 in Sheffield (which had by then become the major steel-producing centre in Britain) as late as 1835.

The production of blister steel in Sheffield cannot be followed on a continuous basis. In fact, the earliest figure seems to be in 1835. Such details as are available are as follows:

Year	Number of Furnaces	Tonnage of Blister Steel
1835	56	14000
1842	97	20500
1846	105	26250
1851		39000
1853	160	40000
1856	206	51000
1861		79000

Comment is made that 45% of the production in 1851 and 65% of that in 1861 was for remelting in the crucible furnaces. The amount of blister steel made thereafter seems to have declined, although the last operation on such a furnace took place as late as 1951.

Crucible steelmaking

Despite the improved product obtained by cementation and subsequent conversion to shear steel, Benjamin Huntsman, clockmaker, of Doncaster, did not find the available steel suitable or reliable for his clock springs. From 1740 onwards he made a series of attempts to emulate the brassfounders and to melt his metal in a crucible. The temperature required, of course, was much higher, but, by use of a deep coke bed and a fierce draught, he eventually was successful in melting a few pounds of steel. By 1761 he was melting around 15 lb of steel at a time and the foundations had been laid for the crucible steel melting process, which, with certain modifications, provided the cutting tools used by engineers throughout the world for well over 150 years. It was, in passing, the first time that liquid steel had been produced in this country, other than probably by accident, and for a hundred years it remained the only known way of producing steel ingots from liquid metal.

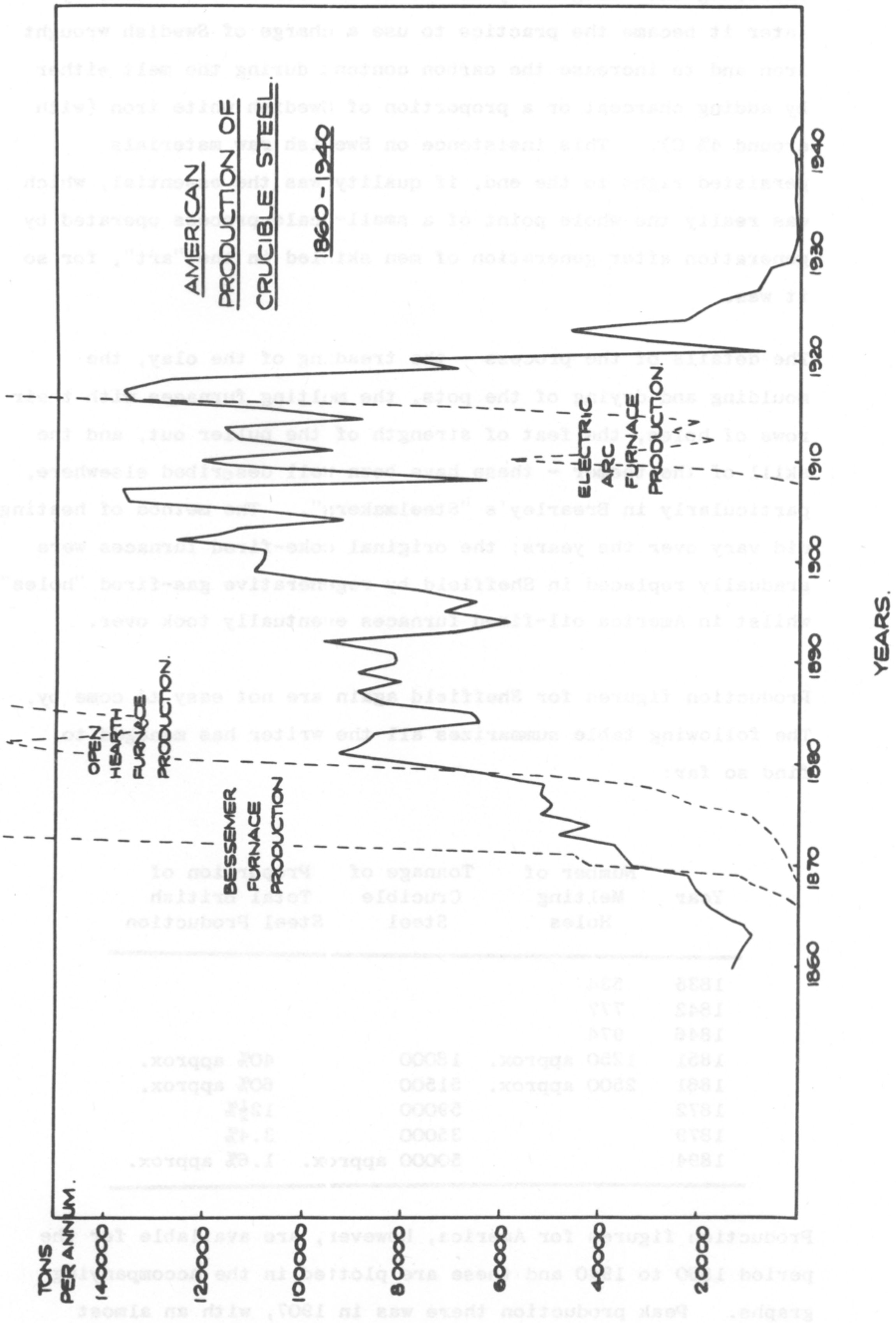
Originally the process remelted blister steel - a method of improving the homogeneity of the material. About a century later it became the practice to use a charge of Swedish wrought iron and to increase the carbon content during the melt either by adding charcoal or a proportion of Swedish white iron (with around 4% C). This insistence on Swedish raw materials persisted right to the end, if quality was the essential, which was really the whole point of a small-scale process operated by generation after generation of men skilled in the "art", for so it was.

The details of the process - the treading of the clay, the moulding and drying of the pots, the melting furnaces with their rows of holes, the feat of strength of the puller out, and the skill of the teemer - these have been well described elsewhere, particularly in Brearley's "Steelmakers". The method of heating did vary over the years; the original coke-fired furnaces were gradually replaced in Sheffield by regenerative gas-fired "holes" whilst in America oil-fired furnaces eventually took over.

Production figures for Sheffield again are not easy to come by. The following table summarizes all the writer has managed to find so far:

Year	Number of Melting Holes	Tonnage of Crucible Steel	Proportion of Total British Steel Production
1835	534		
1842	777		
1846	974		
1851	1250 approx.	18000	40% approx.
1861	2500 approx.	51500	60% approx.
1872		59000	12½%
1879		35000	3.4%
1894		50000 approx.	1.6% approx.

Production figures for America, however, are available for the period 1860 to 1940 and these are plotted in the accompanying graphs. Peak production there was in 1907, with an almost similar figure during the early years of World War I. Such


AMERICAN
PRODUCTION OF
CRUCIBLE STEEL
1860-1940
ELECTRIC
ARC
FURNACE
PRODUCTION
OPEN
HEARTH
FURNACE
PRODUCTION
BESSEMER
FURNACE
PRODUCTION
TONS
PER ANNUM.
14000
12000
10000
8000
6000
4000
2000
1860
1870
1880
1890
1900
1910
1920
1930
1940
YEARS.

a peak, however, only represented around one threehundredth part of the total American steel production.

American production also differed from Sheffield production in the type of pot or crucible used. Sheffield always used a clay pot (at any rate until almost the end of the process) whilst the Americans preferred the plumbago or graphite pot. The clay pot was used only two, or at most three, times; the plumbago pot would do around a dozen melts. The clay pot, however, gave a more reproducible carbon content in the steel; the plumbago pot gave a marked carbon increment which had to be allowed for. Mid-European practice was a compromise, using a 20-40% carbon crucible.

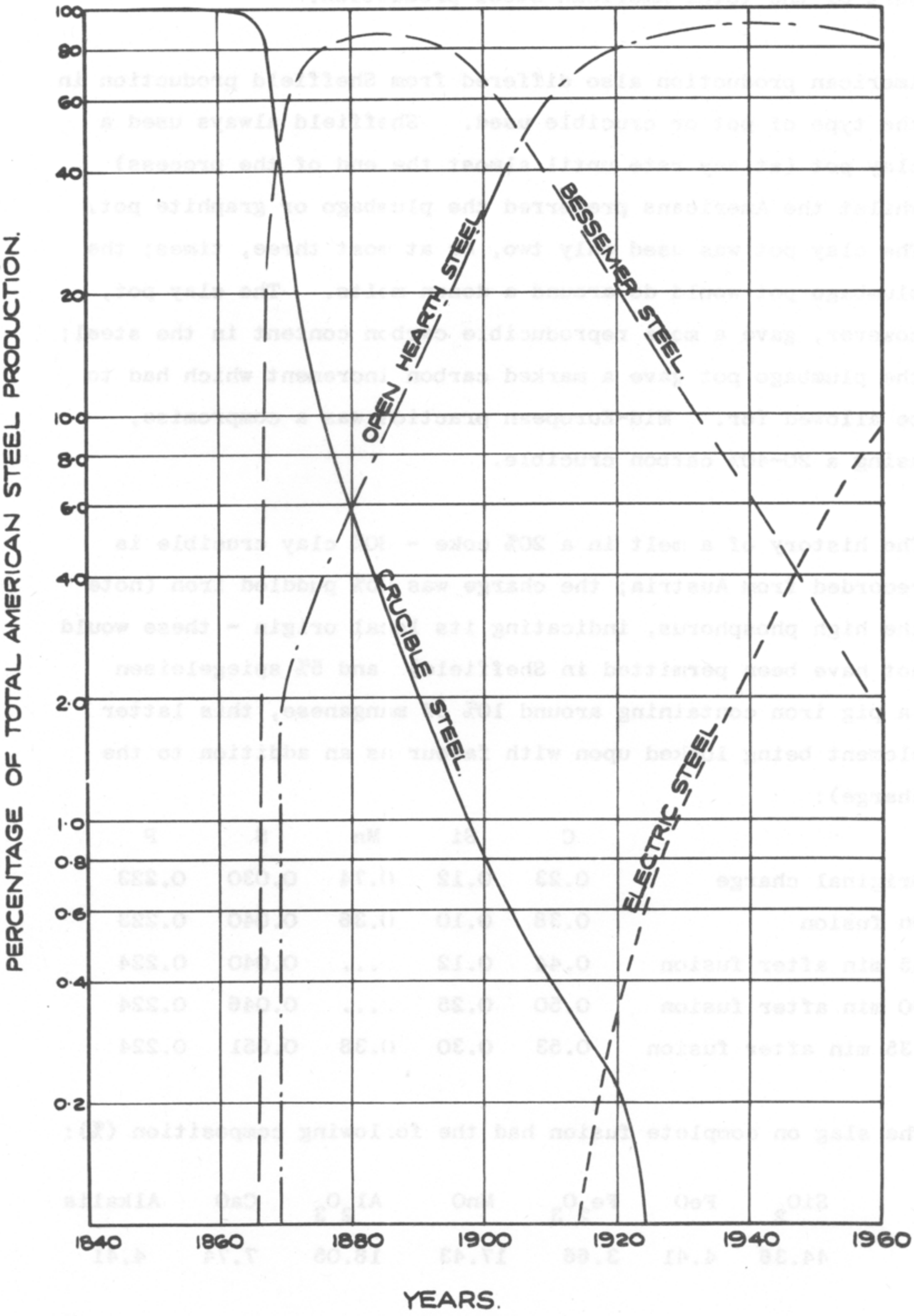
The history of a melt in a 20% coke - 80% clay crucible is recorded from Austria; the charge was 95% puddled iron (note the high phosphorus, indicating its local origin - these would not have been permitted in Sheffield) and 5% spiegeleisen (a pig iron containing around 10% of manganese, this latter element being looked upon with favour as an addition to the charge):

	C	Si	Mn	S	P
Original charge	0.23	0.12	0.74	0.030	0.223
On fusion	0.38	0.10	0.36	0.040	0.223
45 min after fusion	0.44	0.12	....	0.040	0.224
90 min after fusion	0.50	0.25	....	0.046	0.224
135 min after fusion	0.53	0.30	0.38	0.051	0.224

The slag on complete fusion had the following composition (%):

SiO_2	FeO	Fe_2O_3	MnO	Al_2O_3	CaO	Alkalis
44.36	4.41	3.66	17.43	18.05	7.74	4.41

These results show a carbon increment from the carbon in the pot, a silicon increment, a loss of manganese (obviously to the slag), a sulphur increment, from the furnace gases, and no change in the phosphorus content. The silicon increment was probably the most


PERCENTAGE OF TOTAL AMERICAN STEEL PRODUCTION.
100
80
60
40
20
10·0
8·0
6·0
4·0
2·0
1·0
0·8
0·6
0·4
0·2
OPEN HEARTH STEEL
BESSEMER STEEL
CRUCIBLE STEEL
ELECTRIC STEEL
1840
1860
1880
1900
1920
1940
1960
YEARS.

important feature; the gradual rise of silicon content after fusion, brought about by reaction of the carbon, either from the steel or from the pot, with the silica of the slag, which in turn was derived from the pot, brought about the reduction of iron oxide in the liquid metal, this deoxidation process being called "killing with fire". In this way, sound ingots free from blowholes and thus relatively free from segregation were produced.

With the clay crucibles used in Sheffield there was no carbon increment; there was, in fact, some oxidation loss in the early stages of the process. It seems that the losses and gains were not as marked in general in Sheffield practice and it is indeed a pity that no record similar to the Austrian one quoted can be produced as evidence. Some figures can be painfully unearthed, however, and a survey of the charges and final analyses of about a dozen melts of 0.8-1.0% carbon steel appears to indicate an average carbon loss of 0.09% with 0.16% loss in manganese and increments of around 0.05% in silicon and 0.012% in sulphur.

The crucible steel ingot was usually made in a split mould with a cavity of 3in to 4in square. The 3in ingots weighed around 50 lb and took the contents of one pot. The later 4in square ingot, weighing about 90 lb, was produced by pouring the contents of one pot into another, prior to teeming the combined contents. This practice was also employed when slab ingots were required for sheet production; a standard 9in x 4in section ingot, again cast in a two-piece mould, split down the narrow edge and the two parts held together with a hoop and wedges, would also weigh about 90 lb. Square ingots were normally forged to about 1½in square billet for subsequent rolling to bar in the mill. The slab ingot would be forged to a section such as 8in x 1½in for subsequent sheet rolling.

From 1840 onwards there arose a need for larger ingots than the ones we have been discussing for the production of forgings. Engineering was moving away from cast iron and wrought iron;

steel shafts and axles, gun barrels, and the like were deemed desirable. The only way such forgings could be made was to make ingots by teeming the contents of a number of pots into a ladle or a tundish to maintain a constant stream of liquid metal to fill the larger mound. As time went on, larger and larger ingots were required and no sooner do we read of a 7 ton ingot being made in the 1860's, taking the contents of 260 crucibles, than we come across the staggering feat of Vickers in 1870 in making a 25 ton ingot, requiring 672 crucibles to be teemed in around 50 minutes; the organisation was almost a military campaign, starting with the planned commencement of melting in the various locations so that all came together at the right time, and ending with the absolute necessity of keeping the stream of metal into the ingot mould running continuously. One wonders what the homogeneity of such an ingot really was.

The time had obviously come for the newer processes to take over such tasks as they could. Reference to the graph showing the proportions of total production of steel accounted for by the various processes will indicate quite clearly that the bulk steel, particularly in the lower-carbon grades, rapidly became the province of the Bessemer process, to be superseded in due course by the basic open hearth process. Meanwhile, the acid open hearth process steadily became accepted by engineers for the production of the more critical forgings. The crucible process thus found itself more and more the producer of the special small items, and in particular the cutting tools as long as nothing superior to the carbon steel was available. Even when the alloy tool steels, and in particular, the high speed steels, arrived on the scene, they were required in relatively small sizes and the crucible process adapted itself to the making of high speed steel. The old crucible melter, however, will tell you that the art had gone out of the job when the old carbon steel tools were no longer wanted. The "killing with fire" was no longer an essential part; the alloys in the newer steels made the job "too easy". Up to the end of World War I cutlery was still made from either crucible steel or shear steel. But soon after the war, stainless cutlery appeared in every home; the cementation process now was dead and the crucible makers only had high-speed steel to make. Then, in the late twenties, someone invented the high-frequency furnace - "steelmaking in a box," as the crucible man called it. This sounded the death knell of the crucible process and the holes slowly but surely got filled up and covered over.

There was still a last kick in the corpse, however; during the dark days of World War II there was a shortage of steelmaking capacity and a shortage of tool steel; the old crucible men came back and rolled up their sleeves, took off their boots and socks, and trod the clay again; they made their pots; the cellar lad fetched the beer; the puller out wielded his tongs and the teemer doused his "rags" with water and made "ingots with skins like Morocco leather" again. This Indian Summer was a brief one, but it showed Sheffield had not forgotten the art. And the interesting thing is that the American steel production statistics show that precisely the same thing happened over the other side of the Atlantic. After that, the odd furnace lingered on, sometimes doing very odd things, such as casting stainless road studs from cheap scrap! Twenty years later, however, there does not appear to be a single isolated furnace in operation anywhere in the city.

As museum pieces, we now have the last cementation furnace worked by Daniel Doncaster and Company, preserved in the precincts of the British Iron and Steel Research Association in Hoyle Street, Sheffield. We also have the crucible shop in the industrial hamlet of Abbeydale, now mercifully preserved through the cooperation between a few enthusiasts and an enlightened group of City fathers. But the last of the many generations that worked these processes is passing. Surely their recollections should be recorded before it is too late; and the firms in Sheffield, large and small, that operated them should be persuaded to look in their dusty cupboards and find what remains of their records and to see that they are made available to the City Library or to the City Museum in Sheffield. For these two processes became so closely linked with Sheffield that their products earned the city a reputation for quality; moreover, when the bulk steel trade left Sheffield, the skill of the crucible men ensured that the higher priced steels would still be produced in the city and the present-day location of the alloy and special steel trade in Sheffield is a direct result. In 1954 it could be said that Sheffield only produced 4% of the country's steel in bulk, but 54% of the country's steel in value. This is the legacy of the long association of Sheffield with the cementation and crucible processes.

Notes on sites visited during the Second Annual Conference

THE ABBEYDALE INDUSTRIAL HAMLET

The Abbeydale industrial hamlet comprises an 18th century scythe works and workmen's cottages which is currently being restored and will be opened as a museum of Sheffield industry when completed. The site is probably unique in that it is possible to trace the manufacture of a steel edge-tool from the raw materials to the finished product. Also preserved there is an early furnace for producing steel in crucibles of the type developed by Benjamin Huntsman about 1742; the invention of such a furnace laid the foundations for the production of high-quality steel for which Sheffield is world-famous. The works are situated about three and a half miles to the south-west of the city centre between Abbeydale Road South and the River Sheaf.

The crucibles in which the steel was made were produced here and the workshop where the clay was kneaded with bare feet prior to being made into 'pots,' as they were called, is still extant. The high-quality steel was made from a charge of iron and scrap which was heated in the pot for about 4 hours, the requisite carbon being added. The pot was then lifted from the furnace and, after skimming off any slag, the fluid metal was teemed into moulds and allowed to cool to a red heat before removal. When cold the quality of the ingot was tested.

The ingot was then ready to be forged roughly into shape. It was reheated in a hearth in the tilt-forge where the temperature required was achieved by means of an ingenious water-driven air-blowing machine for the fires. The forging then took place under the tilt hammers which were also water-driven. The hammers were lifted by cogs on the wooden main shaft which tilted them to give the correct rapid forging action which was needed to sandwich a piece of carbon steel between an outside composed of wrought iron. Thus great strength and reliability was given to the central cutting edge. The various hand-forges were used by craftsmen who tempered and straightened the blades and also forged other articles from bar steel made under the tilt hammers.

The grinding machinery was driven by an 18 ft water-wheel and during the 19th century a horizontal steam engine was added to provide the motive force in times of water shortage. Adjacent to the grinding shop is the hafting and boring shop which has a further water-wheel used to drive the machinery for these processes.

In addition to the main workshops there is a large warehouse, offices and a row of workmen's cottages. The manager's house was built about the middle of the last century.

The restoration work is being carried out by the Council for the Conservation of Sheffield Antiquities with funds resulting from a public appeal. Although the buildings are almost completed, a further £12,600 is still required to reinstate the machinery. On completion the site will be equipped and maintained as a Museum by the Sheffield City Council.

THE WORTLEY IRONWORKS

The Wortley ironworks, of which the Top Forge is part, have long been famous as probably the oldest ironworks in Yorkshire and their products were greatly esteemed during centuries of useful production for their high quality and sound workmanship.

Production ceased in 1929, since when much of the old equipment, and even of the buildings themselves, has disappeared or fallen into decay. The acquisition of Top Forge, however, by the Sheffield Trades Historical Society ensures the preservation of what remains and also the restoration, in due course, of the working efficiency of this famous 18th century forge, with its two old water-driven tilt hammers, and the water wheel of its blower, along with as many items of the old equipment of the forge as can be collected from various sources, or possibly rediscovered by excavation on the site.

The building has been declared an Ancient Monument by the Ministry of Works, so that its existence is assured, at least in its present condition. It is thanks to the generosity of industrial friends of the Sheffield Trades Historical Society that the building, with its land, has now been acquired and that the most urgent measures of preservation and protection have been so handsomely carried out by its nearest neighbouring great modern steelworks. Further improvements, particularly the restoration to working capacity of the water-wheels and helve hammers, are scheduled by the Society, but the progress of these will be contingent on further generous financial support.

Although this forge is essentially an 18th century building, the existing records of Wortley Forge go back to the days of James I, in 1621, but it is known that the beginnings of ironmaking in the Wortley district stretch back for three or four hundred years further even than that. It may well be true that the Cistercian monks of Ecclesfield, Rockley, Pilley, and Bretton, all places within a few miles of Wortley, may have begun the making of iron at Wortley Low Forge, half a mile lower down the Don from the Top Forge, in the years 1160-1200.

In 1379, the Poll Tax Roll for Wortley contains the names of four "smyths" and of their master, evidence of a forge or bloomery, if only a small one, here at that date. The more material evidence of large beds of bloomery cinder near the forges shows that smelting must have been continued over a long period. There is documentary evidence of a "finery", where pigs of iron were heated and hammered into half blooms and then into ankonies (flat bars with a square knob at each end), at Wortley in the 17th century, and this work was continued at Top Forge until puddling was introduced there by Cockshutt about the end of the 18th century.

By the middle of the 17th century, Wortley Forges were well established. Iron cannon balls, dug up at Low Forge, were proved to have been made during the Civil War period. Examples are preserved in Wortley Church and at T. Andrews & Co., Attercliffe, probably the earliest specimens of Sheffield's armament productions. The names of the Wortley Forges, Slitting Mill and Wire Mills appear in many records of the 17th century, in the families of Cotton, Heyford, Fell, Wood and, especially, Wilson of Broomhead.

Reports of the Wortley Ironworks for the years 1695-6 to 1701-2 are preserved in the records of the famous Spencer family of Cannon Hall, near Barnsley, for Wortley was a member of the Spencer Syndicate. An interesting list of equipment and tools for the year 1696 for Wortley Top and Lower Forges also appears in the Spencer records.

However, the existing Top Forge buildings are of the early 18th century, as can be seen from the stone built into one of the walls bearing the date 1713, with the letters M.W., these being the initials of Matthew Wilson, the then proprietor. A more elaborate stone from the Low Forge, with the date 1713 and the carving of a typical tilt hammer, is now in the possession of Thos. Andrews & Co.Ltd., Sheffield.

In 1739, Matthew Wilson "of Wortley Forge, Gent." died, and his nephew John Cockshutt took over the Works, to be followed by his sons, John and James. In 1771, John Cockshutt took out a patent for refining malleable iron direct from the ore in a finery, no doubt the result of experiments at Wortley.

James Cockshutt was one of the first to appreciate the value of the invention of Cort for puddling and rolling iron, and, soon after 1787, he put down at Wortley the first bar mill with grooved rolls to be erected in Yorkshire. An old rolling mill of this type from Wortley Low Forge has been preserved by the Sheffield Trades Historical Society at Top Forge, Wortley.

At the end of the 18th century Wortley was producing some 300 to 400 tons of high-quality iron, and business boomed during the Napoleonic Wars. Mr. Corbett took over the Works and it was in his time, probably about 1838, that forged railway axles were first made at Wortley, a production on which the later fame of these works was based.

In 1850, Mr.Thos.Andrews, Sen., took over the Works, with his half-brothers, Samuel and John Burrows, under the title Andrews, Burrow & Co. Within a few years the works were enlarged and modernized. A beam engine was installed at Low Forge but the hammers at Top Forge were still driven by water power. Shortage of water was sometimes a problem.

Thomas Andrews, Jun., succeeded his father in 1871, at the age of 24, and he gained international fame as a scientist and metallurgist. The works became famous for the manufacture of railway axles of the highest quality. It was claimed that no "Wortley" axle ever broke in service. Large quantities of bar iron for railway couplings, and for textile machinery, were also produced.

On his death in 1907, the Works were taken over by the Wortley Iron Co.Ltd., under Messrs. J. & B. Birdsell, but they were finally closed in 1929. Wortley was one of the very last to haul down its iron flag before the onslaught of its rival steel.

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THE ROCKLEY FURNACE

The Rockley Furnace, which belongs to the Sheffield Trades Historical Society, is a charcoal blastfurnace located near Barnsley. Although built in 1652, it still retains an inner lining of heat-resisting sandstone blocks cut with such precision as to look like firebricks.

The ground on which Rockley blast furnace stands belonged to Rievaulx Abbey in the 13th century. After an exchange of this land for some in Cleveland in the reign of Edward I, it passed into the hands of the Rockley family. In 1652, Francis Rockley demised to Lionel Copley of Rotherham 3 acres of land at Rockley to build a furnace for which he was to pay £5 a year and a royalty of 5s. per ton of iron made, with liberty to found 40 tons of iron annually. Lionel Copley held it until his death in 1675. About the end of the 17th century, a considerable proportion of the pig iron used at Wortley was supplied by Rockley furnace. A furnace at Rockley was worked by the Spencer family up to about 1750 and was still working in 1795 when the Marquis of Rockingham brought in limestone and smelted the slags of earlier workings with or without the addition of ore. The older slags frequently contained up to 28% of iron which the bloomeries failed to extract. The use of limestone permitted the recovery of nearly all this iron.

The Society's property at Rockley includes a large Newcomen engine house in addition to the blast furnace. The late H.G. Baker stated that it was probably built in about 1740. The engine was used by Darwin & Co. for draining ironstone mines but it was transferred to Hesley Park, Chapeltown, by 1872.

MAGPIE MINE,

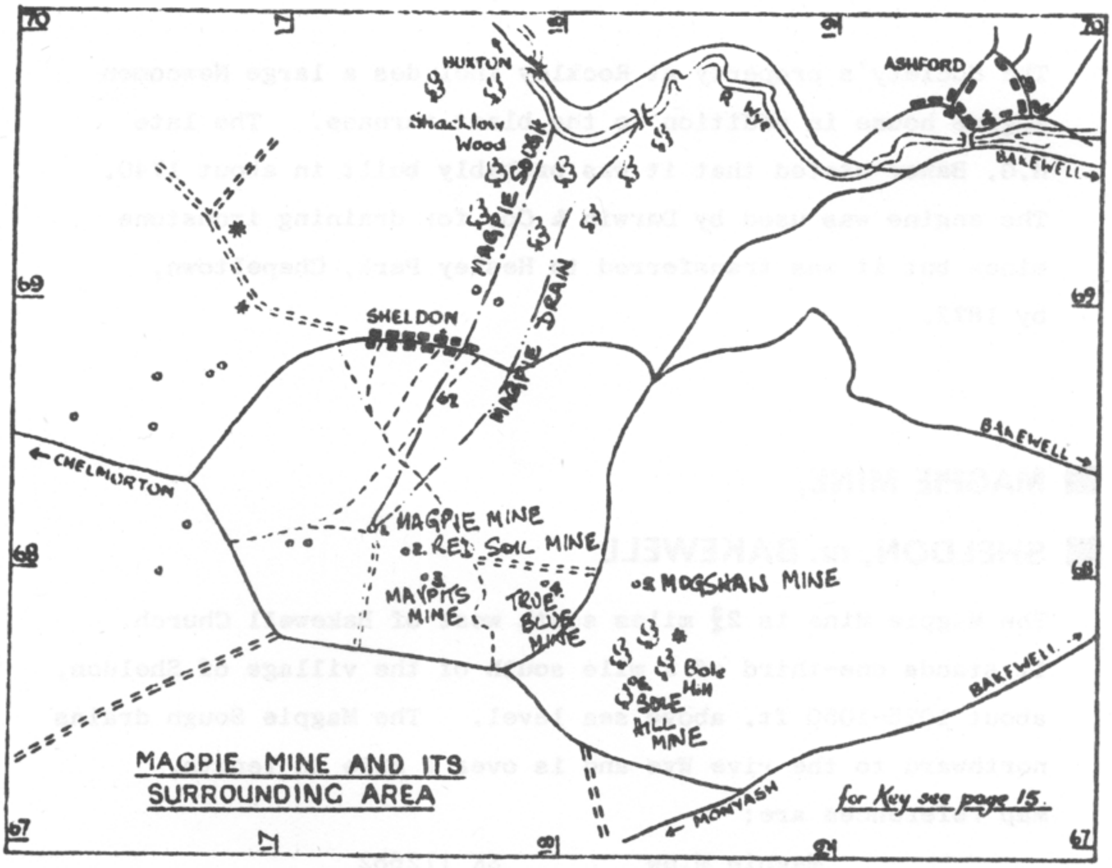
SHELDON, nr. BAKEWELL

The Magpie Mine is 2¾ miles south west of Bakewell Church. It stands one-third of a mile south of the village of Sheldon, about 1025-1050 ft. above sea level. The Magpie Sough drains northward to the rive Wye and is over a mile in length. Map references are:

Magpie Mine	SK 172682
Magpie Sough Tail	SK 179696

The mine is said to be over 300 years old; the first record is that it was being worked in 1795. A Newcomen engine was installed in 1824. Around 1840 a Cornish engine was installed; the building still exists. Water was still a trouble. In 1842 water rose in the shaft "to 458 ft. below surface". A further boiler was installed in 1843 and drains were cut in the surface. Work apparently ceased in 1844.

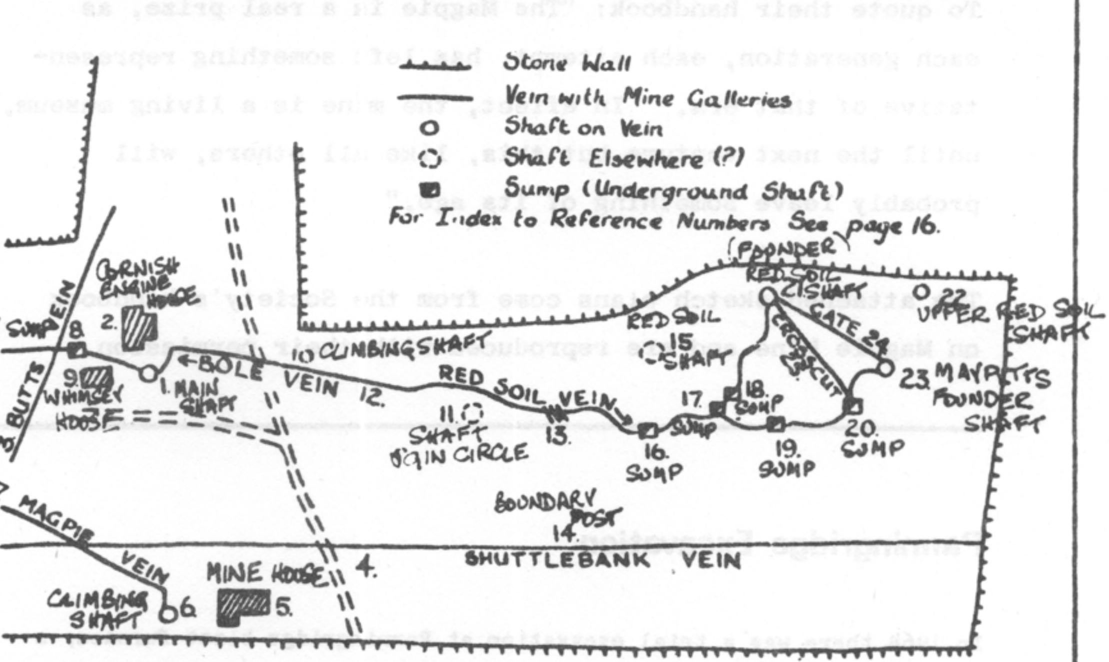
In 1864, the mine was opened up again and a 70 in diameter Cornish beam engine was installed. A horizontal steam winding engine, or whimsey, was added in around 1870; the house still stands but the engine was removed in the early 1950's. As a result of this activity in 1872, the total of 181 tons of lead ore (value £2262) and 61 tons of "linnetts" valued at £244 ("linnetts" was ore long exposed and converted to carbonate) was produced. This made Magpie the third largest lead producer in Derbyshire (beaten only by Millclose Stoop and the Bage Mines).



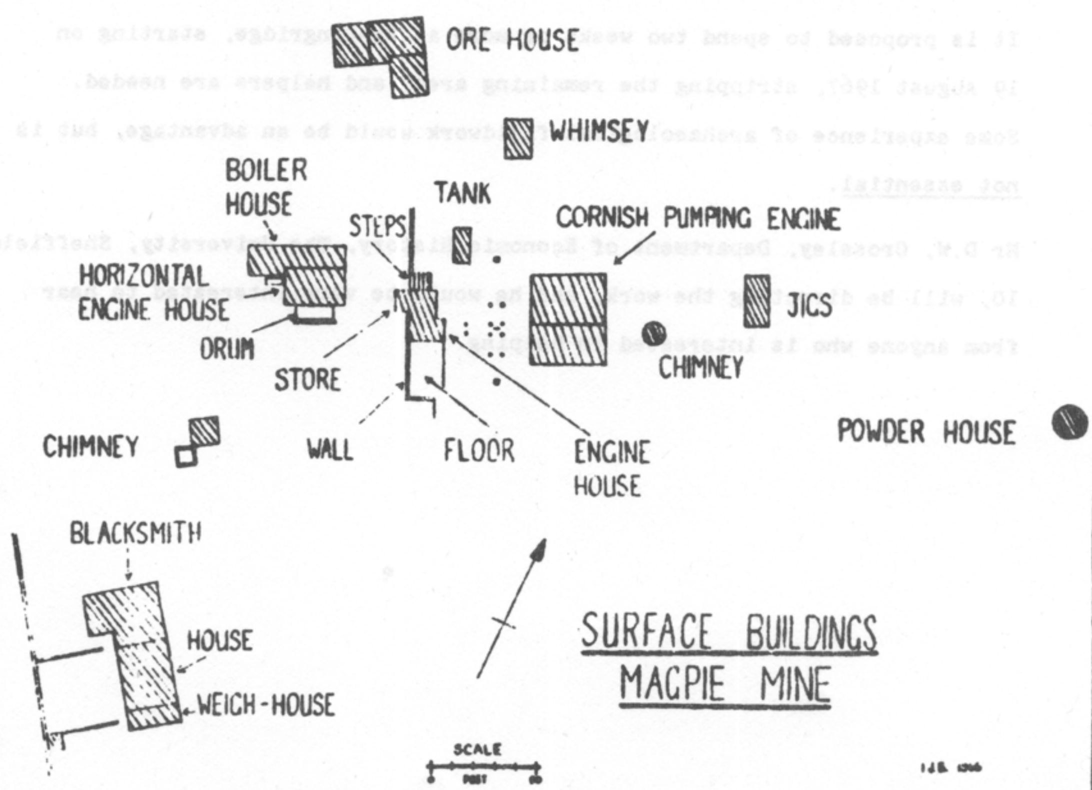
The Cornish engine was effective, but costly to run. It required up to 80 tons of coal per week - a year's supply cost £1432 and it had to be brought by horse and cart from Bakewell station - carriage cost a further £509. For this reason, it was decided to drive a sough from the River Wye to the shaft, to meet it at a depth of 579 ft. This operation took from 3 March 1873 to 18 August 1881, the cost estimated at between £14,000 to £35,000. In 1881, 22 tons of lead ore were produced. In 1882 the figure rose to 523 tons, falling to 198 tons in 1883. In 1884, fire destroyed the Cornish engine. From then to 1919 not more than 5 tons were produced per year. It then closed and was re-opened for the two years 1923-4.

In 1951 the draining of the mine with electric pumps was attempted. Electricity was generated on the site. An electric winder was installed, the whimsey being sold for scrap. By 1953 the workings were pumped dry to 620 ft, but the results were disappointing. By 1958 the price of lead had fallen such as to make further efforts unprofitable.

EASTERN PART OF MAGPIE MINE PROPERTY (FAIR MEER PIECE)



Not to scale. Based on Nellie Kirkham, Sorby Record, Vol. 1, No. 3, 1960.



SURFACE BUILDINGS MAGPIE MINE

In 1962 the tenancy of the mine cottage was taken by the Peak District Mines Historical Society as a field centre. To quote their handbook: "The Magpie is a real prize, as each generation, each attempt, has left something representative of that era. In effect, the mine is a living museum, until the next venture but this, like all others, will probably leave something of its age."

The attached sketch plans come from the Society's handbook on Magpie Mine and are reproduced with their permission.

Panningridge Excavation

In 1964 there was a trial excavation at Panningridge blast furnace, a well documented site used by the Sidneys between 1542 and 1563. Although it was possible to locate the slag heaps, taking samples, and to investigate the construction of the dam, there was not time to trench the area most likely to contain the furnace.

It is proposed to spend two weeks or more at Panningridge, starting on 19 August 1967, stripping the remaining area, and helpers are needed. Some experience of archaeological fieldwork would be an advantage, but is not essential.

Mr D.W. Crossley, Department of Economic History, The University, Sheffield 10, will be directing the work, and he would be very interested to hear from anyone who is interested in helping.

REPORTS ON WORK IN PROGRESS

Minepit Wood, Withyham, Sussex

The smelting furnace excavated in 1964-65, most of which has survived intact, has been dated by carbon-14 determination to 340 A.D. ± 150 years. Although by the margin of error in this test the furnace could be early Dark Age, a Roman date is more likely and this is supported by a few pieces of Roman pottery which were found in circumstantial positions.

This is a very important discovery. It is the first bloomery furnace ever found in the Weald, and it is technologically a very advanced furnace type. The large hearth diameter and provision for blowing through three tuyeres have no parallel in Roman furnaces, either in Britain or elsewhere in Europe.

In 1966 four more furnaces were discovered, three for roasting iron ore and the fourth for smelting it. The slag-heap associated with the smelting furnace produced a few sherds of 14th century pottery, but otherwise there was no dating evidence except various samples of charcoal, which, it is hoped, will also be submitted to carbon-14 tests. The smelting furnace was surrounded by a rectangular structure, of timber on sandstone foundations, which acted as a workshop-cum-depot and included dumps of roasted ore and charcoal for use as fuel.

This spring there will be a short final season with the object of exploring the slag heaps for more pottery and any other occupation material that they may contain. A small structure, possibly another furnace, which came to light at the end of last summer, will also be explored.

J.H. Money

Ruardean, Forest of Dean

The site (SO/615177) is situated in a field north of Warfield Farm, Ruardean, Forest of Dean, alongside a reputedly ancient trackway leading down to the River Wye. The presence of iron-smelting activity was suspected by the appearance of black soil associated with bloomery slag at the edge of a tumpy plateau of land in one corner of the field known as the 'Hops' (O.E. "hop" = a valley).

The disturbed area covered about 60 ft by 50 ft, but it was only possible to carry out a trial excavation on one part of this, owing to the shortage of trained assistance.

An area of about 10 ft x 20 ft was excavated completely to bedrock, where four rock-cut hollows were found at 30in depth, but none of these were considered to have been bowl furnaces, although the sides of two showed traces of heating. Most of the material removed during excavation was tipped back-fill, consisting of black sooty soil (powdered charcoal), masses of bloomery slag and cinder, and numerous stones. In addition to the sooty material, there were pieces of charcoal and also coal. A thick layer of compacted charcoal was found lying on the bedrock surrounding the hollows. Several remains of pit slag lumps, 12-15in in diameter, with dished bottoms, showed that these had been derived from bowl furnaces.

A test hole outside the site showed that the bedrock, at 6in below ground level, consisted of a thin layer of white limestone covering red limestone. The latter was encountered in large quantities from the back fill; many of these had been roughly shaped, and indeed, the side of the working hollow had been revetted with them. Much burnt and unburnt clay was found, but none *in situ*. A quantity of red moulding sand was found in one hollow; the nearest known supply of this is from the Triassic levels near Redmarley, Herefordshire. That the bedrock itself, and also the red limestone blocks, had been exposed for a considerable time was shown by the manner in which the surface had weathered, in some places producing a clayey surface.

Several rims of 13th century cooking pots, together with some medieval green glazed sherds, were found in the back fill. Whilst this only gives a terminal date for the backfill, the absence of earlier material suggests that this must have been a medieval bloomery furnace site. There were also later remains in the backfill, consisting of post-medieval sherds and fragments of clay tobacco pipes.

Clearly, the working area was constructed by digging down to bedrock, the soil being heaped up on the eastern side, producing the plateau. On this the slag heaps would have been tipped, and in later centuries this refuse was filled back into the working hollow.

Reports from local people, together with personal inspection, strongly suggest that the complete northern area surrounding Ruardean was the scene of intensive iron smelting. The nearest source of ore is Hangerberry Hill above Lydbrook, although some may have come from Wigpool Common, both within a distance of 2 - 4 miles. Undoubtedly there is much scope for further work around Ruardean, and there may well be Romano-British smelting sites here.

Thanks are due to Mr. M.Thompson, the owner, for access to the site, and for willing co-operation.

N.P. Bridgewater

CORRESPONDENCE

The Honorary Secretary (Dr R.F. Tylecote) has received the following letter from Dr Robert I. Jaffee of Battelle Memorial Institute, with reference to the paper 'Analyses of Trojan bronzes' (Bulletin, No.7, July 1966, pp.20-29) :

Dear Dr Tylecote,

I was very pleased to see the paper on "Analyses of Trojan bronzes" which you had prepared from the information I supplied. About the only additional information which might have been put into the record would have been to acknowledge the assistance of Mr. Plenderleith, Keeper of the Research Laboratory of the British Museum. He located the missing analyses conducted by Professor Desch. When I looked over the collection of specimens given to us by Professor Blegen, it was apparent that they had been previouly sampled for chemical analyses. An exchange of correspondence finally located the missing analyses in the archives of the British Museum, which is a sort of archaeôlogical find in itself......

With best regards.

Yours very sincerely,

(Signed) Robert I. Jaffee

REVIEW

Bulletin of the Peak District Mines Historical Society

We have received a copy of Vol.2, Part 6 (December 1965, pp.303-368). This is published twice yearly (annual subscription £1.0.0. from 28 Kenbourne Road, Sheffield 7).

The contents of Vol.2 (1963-1965) cover eight items on Derbyshire mines (some running to three parts), items on black marble at Ashford, gypsum working, China clay working, all in Derbyshire, on the South Shropshire lead mining area, on Swaledale mining, on the mineral wealth of Coalbrookdale, two articles on lead abroad, a discussion of Roman mining and one on present-day mining in Derbyshire, together with bibliographical articles.

In the issue on hand, the Editor starts with a plea for accurate recording of descents into old shafts rather than their experience merely as a feat of endurance.

Part I of an article on the Kisdon Mining Company in Swaledale is, in the main, historical accounts of a none-too glorious failure to exploit minor veins of ore in the period 1864-1868.

A note follows on attempted China clay working near Brassington in the late 18th century, apparently essayed because of the interest of Josiah Wedgewood.

The next article is of sufficient interest to merit reproduction in our own bulletin, details of the secular variation of magnetic north from 1580 to date. This has obvious significance in the orientation of old maps and could give some idea of the date of old maps if magnetic north is given and allows for comparison with present-day declination for the identification of old sites.

Twenty pages are then devoted to Part II of an article on Eyam Edge Mines and Soughs (Part III is to follow). The authoress, Nellie Kirkham, is one of the leading figures in this field; her name occurs on three other reports in the index to Part II. This present article appears to be a first-class combination of historical, topographical, and geological information and makes very interesting reading.

A note on the Tri-State Lead Mining district (Oklahoma, Kansas, and Missouri, U.S.A.) follows; the inevitable comparisons with the Derbyshire field are made.

The final item is the second part of an article on the mineral wealth of Coalbrookdale (28 pages). This covers clay, natural gas, oil, copper, lead and sand and also deals with transport. (One presumes coal and iron were covered in Part I). This is excellently produced and the bibliography and notes on illustrations are most full.

Reviews are made of two articles: (a) "Lead mining in Derbyshire in the Mid Nineteenth Century" by G.Joan Fuller (East Midland Geographer, Vol.3, Pt.7, No.23, pp.373-393, June 1965, obtainable from the Geography Department, University of Nottingham) and (b) "The Metalliferous Mining District of Alderley Edge, Cheshire" by G.Warrington (Mercian Geologist, Vol.1, No.2, pp.111-129, obtainable from the East Midlands Geological Society, c/o Geology Department, University of Nottingham). Both these articles would appear to be worthy of further study by those interested.

The issue of the Peak District Mines Historical Society Bulletin under review closes with an extensive index to the whole of Volume 2.

The whole bulletin strikes one as having been tackled in a very workmanlike manner; the articles are somewhat uneven in quality, as is to be expected, and there are numerous typographical errors which would merit attention. An effort has been made, however, to present the necessary maps and plans, and line drawings add to the value. An occasional photographic plate is also interspersed.

It should be pointed out that the Magpie Mine, near Monyash, visited by the members of the Second Annual Conference on September 11, is a site in the care of the Peak District Mines Historical Society. They have issued a booklet on this site, which members found most useful and informative.

ANNUAL GENERAL MEETING 1966

Minutes of the Second Annual Meeting, held in Room 118 of the College of Advanced Technology, Gosta Green, Birmingham at 2.30 p.m. on 26 March 1966.

Present: The President, Sir Frederick Scopes (in the Chair), W.H. Bailey, C.R. Blick, G.T. Brown, D.W. Crossley, B.M. Hardman, M.M. Hallett, G.R. Morton, N. Mutton, A.J. Shore, N. Swindells, and R.F. Tylecote.

Apologies were received from H.T. Angus, F.A. Batty, S.H. Beaver, D. Benson, J.W. Butter, J. Cherry, H.F. Cleere, H.A. Ewings, M.W. Flinn, W.E. Minchinton, W.i. Pumphrey, S.H. Russell, and R.N.M. Ward.

1. **Minutes of A.G.M.** held on 31 March 1965.

These were approved and signed by the President.

2. **Matters Arising**

The Secretary reported that the report on Maryport blast furnace had now been issued and circulated to members. The survey on blast furnace and bloomery sites had been brought up to date and issued in the June 1965 Bulletin. It was reported that an exhibition of slags would be assembled in Wolverhampton College of Technology. Details had been received regarding the horizontal zinc retort at Swansea and it was decided to see what steps could be taken to ensure its preservation.

The Secretary reported that Cornish archaeologists had shown great interest in the short survey on Cornish material in the June Bulletin, and that it was likely that they would now consider doing work on blowing houses and smelters in Cornwall.

3. **The Honorary Chairman**, G.R. Morton, then gave his report on the work of the group during the year. He reported the formation of an active group at the Wolverhampton College. N. Mutton

reported the finding of a bloomery or blast furnace on the site of a village deserted prior to the 16th century in the Clee Hills which he intended to excavate during the period 2-15 April 1966.

4. The Honorary Secretary then gave his report, mentioning that the Group now had over 100 members, had published two bulletins during the year, and had held an autumn conference.

5. The Honorary Treasurer presented an audited statement of account for 1965. This showed that the overall expenditure had been £114 and that the Group had a small credit balance of £14. The conference had yielded a small profit and the main expense was the production and circulation of the bulletins. He moved that the subscription for the coming year should stay at 10/-, and this was accepted by the meeting. The report was accepted.

6. Election of Officers

The following were elected to serve for the year 1966-67:

President	Sir Frederick Scopes
Chairman	Geo. R. Morton
Hon. Treasurer	M.M. Hallett
Hon. Secretary	R.F. Tylecote
Members	M.W. Flinn
	P.G. Rattenbury
	H.H. Coghlan
	C.R. Blick
	M.F. Dowding*
	H.F. Cleere *

* Representing The Iron and Steel Institute

Dr. W.I. Pumphrey was re-elected auditor.

7. Association with The Iron and Steel Institute

The Treasurer reported that following the statement in Bulletin No.6, the scheme for association with The Iron and Steel Institute had now been accepted by the membership and agreed with the Institute. Unfortunately it had not been found possible to extend this arrangement to include the Institute of Metals although it was hoped that this would prove possible in the near future.*

The Treasurer reported that half the membership were members of the I.S.I. This body was in future to be responsible for providing secretarial and editorial services for the Group and would therefore undertake the production and distribution of future issues of the Bulletin. The control of policy and the actual editorship would rest with the committee as at present but members of the I.S.I. could be members of the Group without payment of an additional subscription. As at present, many of the reports emanating from members of the group would be published in the Journal of The Iron and Steel Institute, but would always be made available to members of the group who were not members of the Institute. The Bulletin would exist mainly to report work in progress and news; Bulletin No.6 was an exception to this, being circulated as a vehicle for the Conference papers.

G.T. Brown raised the question of copyright and circulation of the Bulletin to libraries. It was agreed that these matters should be discussed with the Institute.

This arrangement which will relieve the officers of the group of a lot of hard work was unanimously accepted by the meeting.

8. Annual Conference

It was reported that we shall be holding our annual conference at Sorby Hall, Sheffield during the weekend of 9 - 11 September. A committee had been set up under the Convenership of K.C. Barraclough. It was intended to broaden the subject matter of the conference so that there will be contributions on ferrous, lead, and copper-base metallurgy.

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*This has subsequently been arranged; members of The Institute of Metals are now eligible for membership of the Group without extra charge. Professor Hugh O'Neill has been nominated by the Institute as their representative on the Committee.

9. Future Policy

The Chairman introduced this subject with an all-embracing document prepared by H.F. Cleere on the role of the Historical Metallurgy Group. This included a scheme for the organization of research work on the subject, its publication, and services of an advisory nature that might be provided for official bodies. It is also suggested that the Group might undertake the acquisition and classification of industrial archives.

Discussion took place on the question of regional vs. national organization, lead in west Shropshire, and 19th century charcoal forges and fineries in south Shropshire. It was agreed that this document would provide a good framework for the future organization and policy of the Group.

Other items raised under this heading were the broadening of technical college curricula by the inclusion of industrial history and archaeology. W.H. Bailey, noting that the membership of the Newcomen Society was in the range 400-500, thought that it was unlikely that membership of the Group would rise much above 150. He proposed a vote of thanks to the officers of the group for their efforts during the year.

10 May, 1966

SUBSCRIPTIONS 1967

Members of the Group who are NOT Members of The Iron and Steel Institute or The Institute of Metals are reminded that their annual subscription of 10/- is now due. Remittances should be sent to the Honorary Treasurer (M.M. Hallett), Chamberlin and Hill Ltd, Chuckery Foundry, Walsall, Staffs, as soon as possible.

ABSTRACTS

By arrangement with the Editor of the Journal of The Iron and Steel Institute, abstracts of papers of historical interest originally published in the Abstracts section of that Journal are being reprinted in the Bulletin, together with certain other abstracts prepared by members of the Group. Members are invited to prepare abstracts of papers of interest that they may read and send them, for inclusion in the Bulletin, to H.F. Cleere at The Iron and Steel Institute, 4 Grosvenor Gardens, London, SW1.

BRITISH ISLES

Second Interim Report on 'Roman Mine', Monmouthshire. N. and J. Tuck (The British Caver, 1965, Sept., 1-4). The mine is a natural cave, worked over by miners. Finds include Flavian (late 1st century) Roman pottery and a 9th-11th century bone comb. The pottery was in association with a stone hearth, which had heavy spar (containing barytes, chalybite, and hematite) nearby. An extensive Roman lead washing and smelting site lies about 300 ft from the cave; this was operated by the II Legion stationed at Caerleon. Excavation is continuing.

The development of iron smelting techniques in Great Britain. R.F. Tylecote (Organon, 1965, 2, 155-178, reprint)(In English) : (Rev.Hist.Sid.,1966, VII, 2)(In Fr.). A wide-ranging survey based on the published literature and the latest archaeological and metallurgical evidence. Beginning with the Early Iron Age, the study concludes with the use of coke in the 18th century. Accounts are given of the composition of direct smelting slags and residues, the introduction of the blast furnace, furnace construction and profiles, charging and slagging practice, and blast heating, and auxiliaries. Tables provide, respectively, weights of individual iron blooms of varying provenance and date, early furnace yields and details of furnace remains built c.1650-1795.

The Bradley Ironworks of John Wilkinson. G.R. Morton and W.A. Smith (JISI, 1966, 204, July, 661-678). Whereas the exact date of the arrival of John Wilkinson in Bradley is not known, the influence of his contribution to the South Staffordshire iron industry can still be seen. The paper considers how he utilized the mineral wealth of the area, and how, by the introduction of the steam engine, he produced pig and cast iron of high quality. The conversion of the pig to the wrought product was started before the invention of puddling by Cort in 1783-84, and there is no evidence to show that he did adopt Cort's method. The development of the steam driven hammer and the quality of the iron produced are also discussed.

The story of metals Pt.XVI. The struggle to make steel in England - Period 1540-1650. R. Groves (Can. Min. J.,1966, 87, March, 70-72). An historical review.

The second iron bridge. M.M. Rix (Industrial Archaeology. 1966, 3, May, 114-118). The author gives an historical background of the second iron bridge ever to be erected, which was built to span the river Wear at Sunderland in the last decade of the XVIII century.

Iron tombstones and the Pembrokeshire Coal and Iron Company. H. O'Neill (J.Indust.Archaeol., 1965, 2, Dec, 158-160). A description of this Company, formed in 1846, and which probably made some cast iron gravestones found in the Saundersfoot, Pembrokeshire area.

Restoration at Abbeydale. (Engineer, 1966, 221, March 4, 343-344). The historical background of Abbeydale Works in Beauchief, Sheffield, now undergoing restoration is outlined. When the work is completed, it will be open to the public as an industrial museum and will epitomise the long tradition of craft steelmaking in Sheffield.

The Forge Mill, Redditch. J.G. Rollins (Industrial Archaeology, 1966, May, 3, 2, 84-85, 105-107). A brief account of needlemaking, particularly of the 'scouring' (polishing) process in the mill which was in use from the early 18th century until 1958.

The technology of iron manufacture in Britain in the decade 1850-1860. W.K.V. Gale (AIME Met.Soc.Conf., The Sorby Centennial Symposium, 1963, 27, 451-465). Both cast and wrought iron are discussed, in relation to Sorby's work.

Walter Somers Ltd. 1866-1966. W. Somers Ltd. (Metal Treatment, 1966, 33, June, 208-211). A brief centenary history of the firm and its production of forgings.

▪ EUROPE

History of furnace and forging technology in the former Duchy of Berg. E. Stursberg (Beitrage zur Geschichte Remscheids, No.8, Publ. Stadtarchiv Remscheid, Remscheid 1964, pp.120) (In Ger.). A history is given of these industries and their development from the 14th century onwards.

Hungarian iron and steel industry at the beginning of the 18th century. C. Heckenast (Rev. Hist. Sider., 1966, 7, (2), 113-131) (In Fr.). Hungarian ironmaking is shown to have developed to the inception of 'capitalist' modes of production at this period.

Iron objects connected with mining and the iron and steel industry in Bohemian museums (Anschnitt, 1966, 18, June, 31-34). An illustrated account of objects found in the museums in Czechoslovakia.

An ancient steel-making centre in Gory Swietokrzyskie (Holy Cross Mountains). M. Radwan (Hutnik, 1966, 33, (2), 68-71) (In Pol.). A critical review of a paper published by J. Zimny, ibid., 1965, 32, (3).

Ancient Polish iron and steel making technique. M. Radwan (Rev.Hist.Sider., 1966, 7, (2), 63-86) (In Fr.). Archaeological investigations of the iron and steel making in the Monts-Sainte-Croix region, covering in territory of 800 sq.m and 1805 groups of furnaces, are reviewed in detail.

Notes on metal working in the Val Sesia. A. Gaibi. (Atti Notizie AIM, 1966, 21, May, 135-138; published in Met. Ital., 1966, May). The paper refers to Au, Ag, Cu, Pb, Ni, Co, and Fe ore working in the Alpine Sesia Valley in the 15th to 18th centuries. References are made to written records. The area was a major supplier of firearms, weapons, and armour to the famous Milanese market.

Primitive metallurgy in the Alta Valle Camonica. M. Giannoni (Atti Notizie AIM, 1966, 21, June, 169-171; published in Met. Ital., 1966, June) (In Ital.). The Camonica Valley is known from the archaeological record to have been the site of ironmaking from about 1000 BC. However, primitive metalworking processes are still in operation at the present time in the region of Bienno. The River Grigna provides the motive power for a large number of hammers, producing buckets and agricultural implements. The paper describes the method of operation of these hammers.

AMERICA

The production of iron at the Saugus foundry about 1660. C.S. Smith (Rev.Hist.Sider.,1966, 7, 7-15 (In Fr.). The available evidence for the use of a cutting machine for slicing rolled or forged bars, driven by hydraulic power is outlined. The mechanics of the apparatus are described, and the production of iron at Saugus, Massachussets begun in 1647 is outlined. A specimen of a defective partially sliced bar has been found on the site, and metallurgical examination was used to investigate the operations at the works.

METALLURGICAL INVESTIGATIONS

Metallographic studies of an axe from the Migration Age
R. Thomsen (JISI, 1966, 204 Sept., 905-909). This paper describes preliminary investigations on a Migration Age axe head found in co. Randers, Denmark. Cleaning of the head revealed that it had been manufactured from several pieces and the paper reports on the analysis of the component parts and their structures. The component sections were subjected to metallographic examination, and the paper advances preliminary theories as to the mode of construction of the axe head.

PROCESSES

Historical links between metallurgy, alchemy and pharmacy.
W. Schneider (Arch.Eisenh., 1966, 37, July, 533-538) (In Ger.). The origins of alchemy and its relationship to metallurgy are outlined.

The story of metals - Part XIX. R. Groves (Can. Min. J., 1966, 87, July, 69-70). The development of the bellows, the use of coke instead of charcoal in Fe manufacture, and Huntsman's discovery of crucible steel are described.

ECONOMICS

The development of iron prices in the Middle Ages.
R.Sprandrel (Stahl Eisen, 1966, 86, June 16, 726-730) (In Ger.). Details of prices quanitities and weights used in dealings in iron in the Middle Ages, and their comparability are given. An assessment of the value of iron against the prices of other goods and money income (comparison of purchasing power) is made. Comparability of currencies is discussed and examples are given of the development of iron prices.

Iron and steel and economic growth in France and Great Britain (1735-1913) (Rev.Hist.Sider., 1966, 7, 45-53) (In Fr.). The evolution of the iron and steel industry in France and Great Britain is discussed by reference to a book by P.Russo of the above title. The factors, both economic and technical, which influenced the rate of development in both countries are considered. Taking the application of hot air production for use in the blast furnace as an example, the speed of application of a new process is outlined.

The Historical Metallurgy Society was established in 1962, to record and encourage the preservation of early iron blast furnaces in the United Kingdom. Its scope now covers all aspects of metallurgical history and has an international membership which includes members from Africa, Asia, Australia, Europe and North America. Ferrous and non-ferrous interests are equally represented.

From April 1963, the Society published results of its research at regular intervals. Since January 1967, it has produced an annual Journal (originally called Bulletin) issued in two parts, in the Spring and the Autumn, totalling some hundred pages with a digest of abstracts collected from world-wide sources. This is edited by Professor Ronald Tylecote of London University's Institute of Archaeology whilst the abstracts are collated by Dr Paul Craddock from the British Museum Research Laboratory. Occasional Papers are also published and in the past have included *Sydney Gilchrist Thomas and Blaenavon,* to mark the centenary of the Gilchrist/Thomas basic-steel process and a survey of 19th-century blast furnaces in Sweden, edited by Dr Marie Nisser and produced in conjunction with Jernkontorets Bergshistoriska Utskott of Stockholm.