HISTORY OF
THE BRITISH
IRON AND STEEL
INDUSTRY
'Landscape with ironworks and mines' by Henri Blès (before 1550); Uffizi Gallery, Florence (blocks by courtesy of A.C.E.C. Charleroi)
HISTORY OF
THE BRITISH
IRON AND STEEL
INDUSTRY
from c. 450 B.C. to A.D. 1775

by
H. R. SCHUBERT

Foreword by
the President of The Iron and Steel Institute

LONDON
ROUTLEDGE & KEGAN PAUL
To my wife Lotty Violet Schubert
in memory of many quiet years

© by H. R. Schubert

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FOREWORD

by A. H. Ingen-Housz

President of the
Royal Netherlands Blast-Furnaces and Steelworks Ltd.
President of The Iron and Steel Institute

Knowledge of the art of working iron came relatively late to pre-historic Britain. Nevertheless, the 'History of the British Iron and Steel Industry' is a long history. This book covers the first 2000 or 2500 years.

During most of this period the industry was faced with formidable competition from the Continent, where richer raw materials and, in pre-medieval times at least, a higher stage of civilisation resulted in the introduction of improved processes of manufacture considerably before they were known on this side of the channel. Nevertheless, it is a distinguished history. Dr. Schubert draws attention to the skill of British ironmakers who met competition by improvements in technique and the quality of their products.

The book ends in 1775. By that date the inventions of Abraham Darby, of Huntsman and of James Watt were transforming the industry. In that year Cort first acquired a forge and a mill. The industrial revolution was in full swing. The great age of steel had begun. For a hundred years the industry in the United Kingdom was to lead the world. Not until 1872 was as much iron made in all other countries added together as in the United Kingdom, and not until 1886 was the production of steel in the U.S.A. greater than in this country. Neilson, Cowper, and Lowthian Bell revolutionised blast-furnace practice. In the second half of the nineteenth century the inventions of Bessemer, Mushe, Gilchrist-Thomas, Siemens, Talbot, Hadfield and others laid the foundation of modern steelmaking.

When, after the war, the British steel industry was embarking on its new development programme, the Council of The Iron and Steel Institute thought it appropriate that something of this great heritage should be made more widely known. We consider ourselves singularly fortunate to have secured the services of a distinguished scholar, Dr. H. R. Schubert, who was already working on this subject. In 1946 he
accepted the appointment of Historical Investigator. This book is the fruit of his fine scholarship. We wish also to record our indebtedness to Dr. C. H. Desch, F.R.S., who was President at that time and took much personal interest in the development of the work.

It is for me, a President who comes from a neighbouring and friendly country where the steel industry is relatively small and young, an honour as well as a pleasure to commend this book to all interested in the early history of this great industry.

A. H. Ingen-Housz

Ymuiden, Holland

September, 1957

President of The Iron and Steel Institute
PREFACE

In 1935 I conceived the idea of writing a 'History of the British Iron and Steel Industry'. Work progressed slowly both in the early stages, and later when I was lecturing at Reading University. From 1948, however, I was able to devote my full time to this work, thanks to the generosity of The Iron and Steel Institute in London, I owe a special debt of gratitude to the President and Council of the Institute, and to the Secretary, Mr. K. Headlam-Morley, for their support and for the unfailing interest they have shown in the progress of the book.

It is impossible to express my gratitude to all those who have liberally granted access to their archives and collections. They include the Dukes of Devonshire and of Rutland, Lord De L'Isle and Dudley, the Public Record Offices in London and Edinburgh, various English County Archives, the Archives-Nationales in Paris, and the Archives de l'Etat at Liège and Namur. In addition, my sincere thanks are due to the staffs of a large number of Museums and Libraries, particularly the British Museum in London, the National Museum and the Royal Scottish Museum in Edinburgh, the Libraries at Aberystwyth and Cardiff, and the Library of the Verein Deutscher Eisenhüttenleute in Düsseldorf. I am deeply grateful also to those who gave valuable advice and assisted in difficult tasks; I can mention here only Dr. C. H. Desch, F.R.S., formerly Professor of Metallurgy at Sheffield and Head of the Department of Metallurgy at the National Physical Laboratory; the late Dr. H. W. Dickinson, Secretary of the Newcomen Society in London; Dr. William Rees, Professor meritus at Cardiff; Mr. Francis Thompson, M.A., Director of the Devonshire Collections at Chatsworth; Mr. J. Manwaring Baines, B.Sc., Curator of the Museum at Hastings, and last but not least Mr. F. W. Clark, a coal miner at Cwmaman in Glamorgan, who voluntarily in his spare time cleared an ancient furnace of debris. I regret I am unable to mention by name all those who have so willingly helped me. Their number is too great.

Epsom Downs
12th May 1957

H. R. Schubert
INTRODUCTION

THE period with which this book is concerned is essentially marked, and distinguished from any subsequent period in the history of the British iron and steel industry, by the use of charcoal as a fuel for ironmaking. The substitution of coke for charcoal, first introduced by Abraham Darby in 1709, gradually increased in the course of the eighteenth century, so that around 1775 the charcoal-iron industry had practically ceased to exist in Britain except for some isolated furnaces, mainly in remote regions. About the same time a further change, which was of equal importance, came into being. This was the transition from water power, applied to drive the bellows and the hammers, to steam power. The decisive year was 1775, in which James Watt's invention of the steam engine passed from the experimental into the commercial stage. Steam engines began to be supplied commercially, which inaugurated a new era: the age of steam power. For this reason, the year 1775 marks, as Professor Ashton in his standard book *Iron and Steel in the Industrial Revolution* worded it, 'more clearly than most dates selected as boundary-stones the end of one economic period and the beginning of another'.

The history of ironmaking with charcoal is divided into two periods, distinguished from one another by the methods applied, which are generally termed the direct and the indirect processes of ironmaking. In the first, the iron was extracted from the ore directly in a malleable state. In the indirect process this state was not achieved until the iron, produced in a blast furnace as cast or pig iron with a high carbon content, was refined and decarburised in a separate forge. The direct process was used exclusively from the coming of iron to prehistoric Britain until the end of the fifteenth century A.D. It was carried out in small furnaces or hearths which constituted the major equipment of an iron plant then termed a bloomery or bloomsmithy, a term derived from the lump of iron produced, which was known as a bloom. The direct process prevailed in the British Isles until around 1540, after which date the indirect process, using blast furnaces and forges, was adopted more widely than in the initial period of blast-furnace production which commenced shortly after 1490. The blast furnace, which ensured a continuous blowing, in contrast to the furnaces of the bloomeries in which the process had to be interrupted usually once a day for
the extraction of the smelted bloom, was more economical, so that production per unit rose considerably. It also afforded the advantage of enabling leaner ores to be smelted, which was of the greatest importance in Britain.

Compared with other iron-producing countries, such as Austria, Germany, Spain and, above all, Sweden, the sources of high-grade ores were limited in the British Isles. For this reason, as early as in the Middle Ages when the demand for iron increased, a formidable competition arose which seriously handicapped the development of the industry, in particular the production of steel. Foreign iron and steel began to be imported in large quantities. For this reason the history of iron and steel in Britain is largely a history of the ironmakers' skill, by which the disadvantages resulting from the low grade of most of the native ores were overcome. It is a story of invincible perseverance which never shrank from unfavourable conditions nor was defeated by initial failure.
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PRINCIPAL ABBREVIATIONS

AC  Archaeological Collections

Agricola, G., *De re metallica*, translated into English by H. C. and L. H. Hoover, London, 1912


App. Appendix

Arch. Archaeologia

Arch. Jo. Archaeological Journal


Be. Belvoir Castle, Leicestershire, Documents and Accounts concerned with the ironworks at Rievaulx, preserved in the Archives of His Grace the Duke of Rutland.

Beck, L., Geschichte des Eisen, 5 vols., Braunschweig, 1884–1903

BM  British Museum

Boate, G., *Ireland's Natural History*, London, 1652

Bo. Bodleian Library, Oxford

Cal. Calendar

CEH  *The Cambridge Economic History*, vol. 1, Cambridge, 1941; vol. II, Cambridge, 1952


Cork MSS  Manuscripts and documents of Richard Boyle, First Earl of Cork, preserved at Chatsworth, Derbyshire

CRO  County Record Office


Dudley Archives  The Earl of Dudley's Archives, deposited in Dudley Central Library

EcHR  *The Economic History Review*
Principal Abbreviations

EHR The English Historical Review
Fell, A., The Early Iron Industry of Furness and District, Ulverston, 1908
Forbes, R. J., Metallurgy in Antiquity, Leiden, 1950
Fox, Sir Cyril, A Find of the Early Iron Age from Llyn Cerrig Bach, Anglesey, Cardiff (National Museum of Wales), 1946.
Grosart, A. B., The Lismore Papers, privately printed from manuscripts at Lismore Castle, Eire, 10 vols., London, 1886–88
Hart, C. E., The Free Miners of the Royal Forest of Dean and Hundred of St. Briavels, Gloucester, 1953
HMC Historical Manuscripts Commission
Jo. Journal of the Iron and Steel Institute
Johannsen, O., Geschichte des Eisens, third edition, Düsseldorf, 1953
Kelsall, John, Diary (containing notes on ironworks, in particular on the furnaces at Bersham and Dolgyn, 1717–43), Friends’ House, London
L & P Letters and Papers, Foreign and Domestic, Henry VIII
Leigh, Charles, The Natural History of Lancashire, Cheshire, and the Peak in Derbyshire, Oxford, 1700
Lewis, Knights Lewis, R. A. Two Partnerships of the Knights. A study of the Midland iron industry in the eighteenth century. Thesis of Birmingham University, 1949
Middleton Papers, Documents of Lord Middleton, deposited at the University Library of Nottingham
News. Tr. Transactions of the Newcomen Society
NLW National Library of Wales, Aberystwyth
Pe. Penshurst Place, Kent, Documents of Lord de l’Isle and Dudley.
Phil. Tr. Philosophical Transactions of the Royal Society
Principal Abbreviations


Plot  R. Plot, The Natural History of Staffordshire, Oxford, 1686

PRO  Public Record Office

PSAS  Proceedings of the Society of Antiquaries of Scotland, Edinburgh

Raistrick, Dynasty  A. Raistrick, Dynasty of Iron Founders. The Darbys and Coalbrookdale, London, 1953

Raistrick, Quakers  A. Raistrick, Quakers in Science and Industry, London, 1950


SP  State Papers

SPD  State Papers Domestic


St E  Stahl und Eisen


Straker, E., Wealden Iron, London, 1931

Surtees  The Publications of the Surtees Society, Durham and London

Swedenborg, E., De Ferro, Dresdae et Lipsiae, 1734

Tr.  Transactions

VCH  Victoria County History

Woolhope Tr.  Transactions of the Woolhope Naturalists' Field Club, Hereford


Yernaux, Jean, La Métallurgie liégeoise et son expansion au XVIIe siécle, Liège, 1939
PART ONE

THE DIRECT PROCESS
CHAPTER I

THE ADVENT OF IRON

IRON AND BRONZE

The earliest appearance of iron in Britain can be traced back to a remote age which is known as the Bronze Age, since the metal in common use for the manufacture of weapons, tools, and articles of everyday use was bronze, an alloy of copper and tin. The first traces of iron-working were discovered at settlements of Celtic people who first came to England about 800 B.C., probably from northern France. They eventually occupied the south and southeast of England from Cornwall to Lincolnshire.

One of these settlements was at Boscombe Down, in Wiltshire. In a ditch a lump was found which 'might be an early iron slag' according to a statement made after its examination.1 At another settlement, at Plumpton Plain near Lewes, in Sussex, whetstones were discovered, the chemical analysis of which suggested the possibility that iron tools had been used on them.2

A more distinct indication of iron-working is supplied by a hoard discovered in the peat-moss at Llyn Fawr, in Glamorganshire, which may date back to the sixth century B.C. In addition to many objects made of bronze the hoard contained the hilt of a sword, a spear-head, and a socketed sickle, all three made of wrought iron.

The sickle is a painstaking copy of bronze models and was apparently made by a smith trained in bronze-technique who was attempting to master a new material.3 Another example of iron being adapted to a bronze type is an axe with a part of a wooden handle, found on the Berwyn mountains of eastern Merionethshire. Sickle and axe, however, do not signify any settled Iron Age culture in Wales; probably they were either imported in the course of sporadic trade, or were the

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The Advent of Iron

product of casual infiltration by blacksmiths. In the same period iron-working seems to have been known in Ireland also. Knowledge of the craft, however, cannot have been widespread and probably resulted from infiltration, as in England and Wales.

The employment of isolated objects made of iron does not constitute a distinct stage of metal culture. It was only when iron ores began to be exploited on a commercial basis, and the production of iron was sufficiently plentiful for industrial use, that a new phase began. This is called the Iron Age, in which we are still living.

Compared with iron-producing countries on the Continent, in Britain the age of iron came rather late; its beginning can hardly be dated earlier than about 450 B.C. In central Europe, in the Austrian Alps, iron had been used since about 1000 B.C., first for ornamental purposes, but soon for tools and weapons also. In the next two hundred years bronze and iron were used side by side, but from 800 B.C. iron predominated. The iron products of this region were discovered in some thousand graves dating from about 1000 to 700 B.C., situated near the salt-mines of Hallstatt in Upper Austria. The splendour of the Hallstatt civilisation is represented by a rich collection of iron weapons, utensils, knives, files, anvils, and other articles. Similar treasures were discovered 200 miles south-east of Hallstatt at the cemetery of Magdalenaaberg.

From the Alpine region of Hallstatt the craft of manufacturing iron for the requirements of everyday life and for weapons spread among the peoples living south and north of the Alps. It was not before 450 B.C., however, that the iron-working craft was brought to the British Isles by immigrants from Europe to such an extent that the new metal came into common use. Even then, it still had to compete with bronze as an industrial metal for a considerable time.

For several centuries prior to 450 B.C. the market for metal work was dominated by an old and well-established bronze industry which reached its zenith in Britain in the so-called Late Bronze Age (1000 B.C. -500 B.C.). More bronze-casting was practised in this period than ever before. It had even developed on new lines on account of the introduction of valve moulds, i.e. clay moulds consisting of two parts, or valves. In this respect bronze had a distinct advantage over iron, which was not cast in those days. Further, in the Late Bronze Age an improved technique of hammering was employed which rendered it possible to produce, shape, and decorate large sheets of metal. In the same period the supply of copper from Ireland was supplemented by the exploitation of new deposits of ore in Wales, northern England (e.g. Weardale ores in the present County of Durham), and even in Shetland. The intensified activity is reflected in the numerous hoards of founders' and smiths' tools which have been found. Hoards of tools employed by

travelling British-Irish bronzesmiths were discovered on the Continent also. A typical example is a kit of tools, which was found at Fresné-le-Mer, Calvados, in northern France, and is now in the Ashmolean Museum, Oxford, comprising an anvil, hammer, and curved knife. British metal workers were producing for, and selling on, the Continental market. British and Irish objects made of bronze were exported as far as the southern coasts of Spain, and eastwards to the middle Elbe and the shores of the Baltic sea. The strength of the economic position which the British-Irish bronzesmith held in the Late Bronze Age, which was based on his knowledge of superior techniques such as the art of casting, was responsible for the late introduction of iron into the British Isles.¹

With the expansion of the iron-using Hallstatt civilisation, however, the European market for the British-Irish bronzesmith began gradually to contract. The new iron industry, although technically not yet sufficiently advanced for production on a large scale, had an important economic advantage over the bronze industry in as much as it was able to produce at a lower price. The production of iron required a less complicated organisation than bronze-making, which depended on the combination of two metals, copper and tin. In addition, the ores of iron are much more abundant and more widely distributed than those of copper and tin. All this made iron tools cheaper and brought them more within the reach of the common purchaser, so that they could be universally used for agriculture, for the clearing of forests and the draining of marches, and for other purposes which required heavy work. Iron made man better equipped in his struggle with nature and with his rivals.² In the competition between the British bronzesmith and the Continental blacksmith which first developed on the central European market in the course of the eighth century B.C. and gradually extended westwards, the deciding factor was the cheapness of the new metal. It secured the blacksmith the ultimate victory over his more ancient rival.

THE IRON- USING COMMUNITIES

The period in British history which commenced with the advent of iron about 450 B.C. and ended with the Roman conquest in 43 A.D. is termed the Early Iron Age. It is generally subdivided into three periods: Iron Age A from approximately 450 to 250 B.C.; B from approximately 250 to 75 B.C.; and C from 75 B.C. to 50 A.D. The subdivision is based on the different cultures brought to the British Isles in these phases by immigrants who came in successive waves from the Continent. All of them were of Celtic race, except the Belgae of the last period who were partially Germanic.

¹ Childe, pp. 172–178.
² Forbes, pp. 32–33.
Iron Age A (about 450–250 B.C.)

The first wave of iron-using Celtic immigrants, who reached the coast of England from the Low Countries and northern France shortly after 450 B.C., originally came from the Rhine valley, which they had left under the pressure of German tribes from the north-east. They settled in the south and in the east of England spreading north as far as Scarborough, in Yorkshire. They did not penetrate into Upland Britain, their settlements remaining confined to the lowland zone, south-east of a line drawn from Dorset and west Somerset to Lincolnshire and the East Riding of Yorkshire. Probably all were accompanied by blacksmiths able to provide the farmers with bill-hooks, sickles, and narrow ploughshares. In the beginning of this period bronze was still employed even in the manufacture of tools; for ornaments it was used everywhere; thus the period was a phase of transition from the old to the new metal. All these early invaders were affected more or less by the culture which had developed in the Hallstatt region, in the Austrian Alps. Their economy in Britain was based on farming which, however, was still supplemented by hunting.¹

A typical settlement of these Celtic immigrants was at All Cannings Cross, about 6 miles east of Devizes, in Wiltshire. It was an open village surrounded by a palisade which enclosed a circular yard 400 feet in diameter. The inhabitants lived in wooden huts and used bell-shaped pits, 8 to 10 feet deep, as silos for the storage of grain. The finds discovered suggest that the village was erected somewhere about 450 B.C. and was inhabited until about 300 B.C.²

Of the finds many were still of bronze, side by side with iron objects. The iron objects of All Cannings Cross include implements such as gouges which were probably used for working wood, knives with curved blades (a), one blade of a pair of shears the point of which is missing (b), and several awls.

The pins found indicate a change of fashion which had taken place by that time. In the earlier part of the Bronze Age the people of Britain generally wore a buttoned costume which was fashionable in Atlantic-Mediterranean countries. Hallstatt invaders introduced a new fashion prevailing in central and north Europe. Instead of buttons, pins were used for fastening the garments. The oldest type was the swan-neck pin (c). It is rare in Britain and France. In England³ this type was improved to form the ring-headed pin, specimens of which, made of stout iron wire, were found at All Cannings (d). For ornamentation of the top part beads were used. A third type is represented by a pin with


³ Childe, p. 203.
Fig. 1. Iron objects from All Cannings Cross, Wiltshire.
From Cunnington, plates 20 and 21.
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a round head (e) which is rather flattened; below the head it has a spherical collar of beads.

Of a later period, approaching 300 B.C. which marks the end of the settlement, are the iron brooches. One of them (f), fairly well preserved though much corroded, was made of one piece of stout wire. The bow was bent down across the pin, and the spring was coiled on either side of the head.

Although the early settlers lived mainly in open villages and isolated farms, they also had fortified strongholds on many hills. Beginning in the fifth century in a region south of a line from Weymouth to the Wash, they served as places of refuge in case of swift raids, but they were not sufficiently fortified to stand long sieges. Such common strongholds signify some degree of cohesion between the local settlements clustering around them.¹ From about 300 B.C. onwards some of the strongholds were enlarged and their defences strengthened, and new ones were erected. A new type of hill-forts evolved which were regular fortresses capable of standing a prolonged siege: Cissbury near Worthing, in Sussex, which covered an area of 60 acres, was the largest of these. They became a necessity when new waves of iron-using Celtic tribes reached the British shores. With their arrival a new phase of development commenced.

Iron Age B (about 250–75 B.C.)

The newcomers brought with them a new culture which represented the culmination of early Celtic achievement. It is named the La Tène culture after a village on the shore of the lake near Neuchâtel, in Switzerland. The new culture had developed first in the north-west of Switzerland, in south Germany, and in eastern France. It had evolved from the old Hallstatt culture, but had taken a different course on new lines, mainly on account of contact with Mediterranean civilisations such as those of the Etruscans in Italy and the Greek colonists at Marseille. Celtic craftsmen learned to produce necessities of everyday life which had not been known to the earlier peoples, such as chains and pot-hooks. In decorative art they developed their own style which became emancipated from the classical models of Greek art. The orderly spirit of classical art was replaced by a free, flamboyant, visionary style which yielded ‘one of the most masterly abstract arts which Europe has known’. In the British Isles this new Celtic style was destined to find its last and most mature expression.²

The Celts of the La Tène civilisation invaded Britain around 250 B.C. They came in several groups which occupied the east coast. The most important group settled in the Wolds and on the limestone hills of East Yorkshire north of the Humber and east of the marshy vale of York, and

¹ Curwen, loc. cit., p. 232.
spread south into Lincolnshire, Cambridgeshire and Suffolk. They were land-hungry bands of warriors who came from the Marne district in north-east Gaul. They had iron daggers and broadswords which were carried in richly ornamented bronze-sheathed scabbards. The main characteristic of their culture was the two-wheeled chariot used in war (Pl. I). The chariot was drawn by two horses and equipped with wooden wheels, 1 1/2 inches wide and between 2 1/4 and almost 3 feet in diameter, cased in iron tyres. The wheels were fastened to the axle with iron Lynch-pins.

Another group of invaders landed round the Firth of Tay and Moray Firth in Scotland. They entrenched themselves in powerful hill-fortresses, known as Gallic forts, with 10 to 20 feet thick ramparts of roughly squared stone blocks held together with timbers. The new settlers initiated the Iron Age in Scotland. In the second century B.C. they seem to have reached the west coasts of Inverness and Argyll and thence Galloway, North Wales, and North Ireland. A proper iron-using economy, however, seems not to have commenced very early, possibly not before the beginning of our era.1

A different group of Celtic invaders, who reached the British shores in the second century, came from Brittany. They first occupied Cornwall, attracted by tin mines, for the protection of which they built the hill-fortress of Chûn Castle. From Cornwall they penetrated into the western counties. From Somerset they passed on to the Cotswolds and by the basin of the upper Thames to the Midlands and, it is believed, across the Severn into South Wales. The culture they introduced finally culminated in the lake-village of Glastonbury, in Somersetshire.2

At the beginning of this period the population was much larger than it had ever been before. Only a considerable population could supply the large labour force required for building several hill-fortresses at the same time. The hill-forts still seem to have served mainly as places of refuge in war for the neighbouring population and their cattle, although a small area within the fort was sometimes occupied by dwellings, while other dwellings stood immediately outside the ramparts under their shelter.3

A typical site of an inhabited place is the Caburn, 2 miles south-east of Lewes in Sussex. It was certainly inhabited during the first two centuries B.C., first as an open village, but by about 100 B.C. was surrounded by a rampart. The total population has been estimated as about 200 to 300 souls. The absence of fields in the vicinity, and the discovery of foreign coins, suggest that the place served the surrounding districts as a kind of market-town, and this is confirmed by finds indicating that metal goods were manufactured. Crucibles for smelting

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1 Childe, pp. 9, 212 et seq., 258 — J. Raftery, Prehistoric Ireland, p. 185. London, 1951.
2 Hawkes and Kendrick, loc. cit., pp. 176 et seq.
3 Childe, pp. 198-200.
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bronze were discovered and also an iron hammer-head. Iron was forged into tools such as ploughshares, sickles and bill-hooks, which could hardly have been useful to the inhabitants, who grew no corn. Apparently such articles were exchanged with villagers of the vicinity for corn, milk, meat, flesces and other products of the country. The inhabitants had iron swords and daggers; they used iron razors for shaving, and fastened their garments on the shoulder with brooches of iron or bronze. The brooch constructed on the principle of the modern safety-pin with a spring-pin was introduced from the Continent by the Celtic immigrants of this period. The fashion became universal in England, but did not take root either in Scotland or Ireland.1

A village of a completely different character was Glastonbury in Somerset. While the Caburn was situated on a hill, Glastonbury was built on an artificial island in a lake. The village had an inhabited area of some 3 1/4 acres surrounded by a palisade. More than 60 floors of circular huts were discovered. Here bronze and iron were worked. The blacksmith supplied iron sickles and bill-hooks and forged chisels, gouges, saws, awls, files, bolts, and nails for artisans. The iron bits by which the horses were controlled were of the two-piece type, in which the jointed mouth-piece consisted only of two links with round rings for the reins. Amongst the iron objects discovered there were thirteen knives chiefly used for domestic purposes, one of them being double-edged, five finger-rings, and one key or latch-lifter for lifting the latch of the hut-door. Iron objects of a type similar to those used at Glastonbury have been found all over England from Somerset to Kent, in Derbyshire, in Scotland, and at some places in Ireland, showing that the Glastonbury finds are typical of the objects manufactured in Britain in the period concerned. Of particular interest are the saws, because the apices of the teeth are set in an opposite direction to those of the ordinary modern saw, so that when used for sawing wood, the blade was drawn towards the operator, as with oriental saws.2

The Glastonbury settlement existed from the second century B.C. until it was destroyed in the middle of the first century A.D. By its position it was well fitted to be a commercial centre. A waterway to the Bristol Channel which was only 12 miles distant made water-borne traffic possible. Trackways led to Northamptonshire, and along the Chalk Downs into Sussex. That the village really was a centre of trade is borne out by the discovery of currency bars.3

Currency bars are curiously shaped objects of iron mostly about a

3 Childe, pp. 234-240.
yard long and resembling a half-finished sword, having a roughly formed handle at one end and being slightly hammered at the other. Caesar, who was in England in the years 53 and 54 B.C., reported that the British used either bronze or iron bars of standard weight as money.\1 Currency bars were discovered in large quantities in south-west England from Worcestershire to Somerset and the Isle of Wight, but very few have been found in the south-east and the east of the country, where the Belgae introduced coins around 75 B.C.

Based on Caesar's statement and on comparison of numerous bars, standard weights have been elaborately worked out with a unit of 11 ounces, fractions and multiples, but many of the bars do not at all conform to the standard weights.\2 The currency bars were used as merchandise in barter trade in exchange for other goods such as corn, cattle, etc., or delivered as dues to the chief in iron-producing districts and subsequently forged into desired shapes in the chief's smithy, which constituted an essential part of his establishment. The smith forged the bars either into swords, or into articles of use, as is indicated by archaeological evidence. At Wookey Hole, a prehistoric cave in the Mendips, in Somerset, a bucket was discovered the iron handle of which was exactly of the form and size of one of the complete currency bars. As to the manufacture of swords from these bars: it has been objected that they contained too much metal for this purpose: but in fact the practice of hand-forging meant that the amount of metal could be reduced until only so much was left as to be convenient for the purposes of the grinder who finished the blade.\3

Pieces of unworked iron assembled in hoards for barter trade, with the ultimate object of forging them into implements and weapons, belong to a very early period in Antiquity. A hoard of about 160 tons of unworked iron bars was discovered at Chorsabad near Nineveh in the palace of Sargon II (721-705 B.C.), and the Spartans traded iron

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\1 'Utuntur aut aere... aut taleis ferreis ad certum pondus examinatis pro nummo,' Caesar, De Bello Gallico, v. 12.

C+: H.I.S.
in the form of bars. Pieces of unworked iron from the prehistoric Celtic era have also been discovered on the Continent in great quantities in Switzerland, on the Rhine, in the east of France, and on the upper Danube. They are mainly of two different types, one in the shape of a spindle, somewhat resembling those found at Chorsabad, the other similar in shape to that of the English currency bars; the second type was in use on the lower Rhine. The custom of rendering this form of tribute to the lord in iron-producing districts was still very much alive in the early Middle Ages both in England and in West Germany. In Sweden similar bars, some of which were spade-shaped, others scythe-shaped, were found in great quantities dating from the beginning of the Christian era to A.D. 1050. To sum up briefly: it may be said that the bars found in the various countries, including England, are semi-finished products used as merchandise in a barter trade of fairly considerable extent.

Iron Age C (from approximately 75 B.C. to A.D. 50)
The third period is marked mainly by the invasions of the Belgae, a people of mixed Celtic and Germanic origin, occupying a part of Gaul between the Seine, the Marne, and the lower Rhine. They came in two waves. About 75 B.C. an eastern invasion commenced: Kent first, and later Hertfordshire and Essex were occupied. A second Belgic invasion took place about 50 B.C. which seems to have been led by Commius, king of the Atrebates, who had their capital at Arras in northern France. The last-mentioned invaders mainly landed at the Hampshire harbours; they occupied Hampshire, Wiltshire, and Berkshire, and founded the city of Silchester which later became Romanised.

The general effect of the Belgic invasions was the establishment of larger and more powerful kingdoms instead of the small tribal units which characterised the political pattern of the preceding age in these parts of the country. Finally Cunobelin—Shakespeare’s Cymbeline—became overlord of all the Belgae and of almost the whole of southeastern Britain, which he ruled from A.D. 5 to 40 from his capital at Colchester. Between 50 B.C. and A.D. 43 the west of Sussex also seems to have come under the domination of the Belgae, but east Sussex remained independent.

The organisation of the former small tribal units into larger kingdoms made the old fortified hill-towns unnecessary, and situated as they were on bleak and waterless hill-tops they were unsuitable for market-towns. Thus by 50 B.C. almost all of them were abandoned. The Belgae were

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the first to build cities in the lowlands. Cultivation of low-lying areas was immensely facilitated by a new and more powerful type of plough which they brought over with them from the Continent. Up to then the light Mediterranean plough introduced by early invaders had been used for tilling the soil. It had a wooden ploughshare but no coulter. The point of the ploughshare remained unprotected until iron became cheap, and was more generally used in rural economy, but even then, extra iron was only used to make a protective shoe for the blade. Such a light plough drawn by two oxen only scratched the soil, and for this reason it was mainly suitable for cultivating the light soil of the chalk Downs. The Belgae introduced from the Continent a new and more effective device which had been invented somewhere between Denmark and Bavaria. This was the heavy wheeled plough drawn by four and sometimes more oxen (up to eight). The iron ploughshare was broad and an iron coulter for cutting the turf was in front of it. The heavy plough with iron coulter and ploughshare, capable of turning a proper slice even in clay soil, made it possible to extend agriculture from the chalk Downs to the lowlands. In this way, the Belgic invaders initiated in England an agricultural revolution which was extended and completed by the Anglo-Saxons.¹

Other relics reflecting economic and social conditions in the last phase of Celtic culture in Britain are the gang-chain and the firedog. Gang-chains for slaves and captives have been found principally in the east and south-east of England. One of them, discovered at Lord's Bridge, Barton, in Cambridgeshire, is 12 ft. long with 6 hinged collars which were placed round the slaves' necks. Slaves were sold to the Continent even before the Roman occupation of Britain, in exchange for oil and wine. They were also sold inside the country, which is shown by the discovery of slave-chains in Anglesey, which had been obtained from eastern England in the first half of the first century A.D. In one of these chains the distance between the captives' necks is not more than 2 ft., which is the same distance as in the chain found at Lord's Bridge.²

Signs of wealth and luxury in the English Lowlands, which prospered in the latest Celtic period, are the ornamented wrought-iron firedogs designed for the central hearth of the hall. Their main characteristic is the terminal, forged into the form of an animal's head, in most cases resembling the head of an ox. These firedogs were either double or single-ended. An early example of a single-ended firedog was found at Bigbury Camp in Kent, some two miles west of Canterbury; it is now

in the Maidstone Museum.\textsuperscript{1} The main piece of the animal-body represented by the firedog consists of a rectangular bar beaten flat in its central portion. Two curved bars which carried the feet (now missing) are welded to it, and two small pieces, apparently representing the ears, are welded on to the head, which at its extremity is skillfully beaten into the form of a snuffling muzzle. This low type of firedog, which may have supported the fire-irons rather than the burning log, represents a style characteristic of the period in which Celtic art was at its height in Britain. It reflects the British smith's control over his iron as a medium of artistic expression, and his feeling for good curvilinear design. An early example of the double-ended firedog, closely related in style and technique to the one found at Bigbury, was discovered at Lord's Bridge near Barton, in Cambridgeshire. The two ox-heads are vigorously modelled, the nostrils and eyes being cleverly indicated by sharp blows of the hammer.\textsuperscript{2}

At a later stage firedogs became larger and more elaborate but also a more conventionalised style was introduced, which is shown in a firedog found at Capel Garmon, in Denbighshire (see Pl. II). This work was probably produced in the first half of the first century of our era.

The two uprights, standing on arched feet and joined by a cross-bar, are made of square bars bent outwards at the top in the form of a horned animal's head. A mane is formed by a row of knobs at the outer edge. The sides have iron bands attached to them and these are bent into loops to hold spits for roasting; larger spits were held by the horns of the head. The lowest loops are just above the arched feet. Because of the position of the loops, each pair could be used in turn according to the nature of the cooking and the height of the fire.\textsuperscript{3}

These examples are meant to present no more than a few striking features, illustrating the early use of iron and the achievements arrived at in the production of various iron objects, some of which are of great artistic merit.

\textsuperscript{1} Reproduced Arch. J., vol. lxxxix, Plate m B.

\textsuperscript{2} Arch. J., vol. lxxxix, pp. 110-111—Illustration of the firedog from Lord's Bridge, VCH, Cambridgeshire, vol. i, Plate vni (facing p. 298).

CHAPTER II

PREHISTORIC IRONWORKING

ORE AND FUEL

The elaborate ironwork produced in the latest phase of the prehistoric era is splendid testimony to the skill of the British smith in handling the metal. The metal itself was a soft wrought iron, the ferrous portions of which favourably compared with the best modern wrought iron.¹

Mineral resources

The composition of the metallic part shows that carefully selected ores rich in iron and comparatively free from impurities were predominantly used.² The principal resources were haematites, and in addition bog iron ores, exploited mainly in the north of Britain and Ireland.

Haematite in the anhydrous form, i.e. free of water in combination, is known as red haematite. It is the richest of all iron ores in Britain, but the supply is now almost exhausted. Ores of this type were formerly worked intensively in the vicinity of Whitehaven in Cumberland, and in Lancashire, especially in the peninsula of Furness. They have a high content of iron, usually between 50 and 66%, and are almost free from impurities such as phosphorus and sulphur which are undesirable because of their adverse effect upon the iron. There is, however, no indication that the ore was mined earlier than in the Middle Ages, except possibly in the peninsula of Furness where red haematites weathered on the outcrops may have been exploited before our era.³

Haematite ore containing various proportions of water in combination is known as brown haematite or limonite. Nodules occurring north of the Celtic hill fort of Hunsbury, in Northampton, and in Somerset were worked before the Romans came.⁴

¹ Fox, p. 84; cf. App. I—Wrought iron contained mostly less than 0.1% carbon, in modern terminology it would be classified as Low Carbon Steel.
³ F. Barnes, Barrow and District, pp. 13-14, Barrow-in-Furness, 1931.
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The brown haematite deposits of the Forest of Dean in Gloucestershire, with up to 58% of metallic iron content and almost free from the above-mentioned impurities, constituted one of the most valuable ore resources in Britain and were mined until late in the nineteenth century. Although direct evidence is lacking, there is a great probability that the ores were exploited by native miners and ironworkers before the Roman occupation. The embanked hill-town at Lydney, in the vicinity of which iron ore was mined in the Roman period, was established before the first century B.C. A further indication is the name 'Scowles', applied to ancient iron mines near Bream and Coleford, which seems to be a corruption of the Celtic word 'crowll' meaning a cave. The distribution of the iron currency-bars also indicates the Forest of Dean as a most important source of iron. Four-fifths of the bars were found within a radius of 40 miles of the Forest ore-field.¹

It is not impossible that the brown haematite ore of the Mwyndy mine near Llantrisant, in Glamorgan, which was worked in the Roman era, had been exploited earlier.² Surface deposits of brown haematite may have been mined for smelting in prehistoric Weardale, in County Durham. Slag used for iron-smelting in the Middle Ages, was apparently the refuse from a prehistoric ironworks, since it was obtained from Hoppyland which had been a camp in Britain in pre-Christian times.³

The slag found at All Cannings Cross, in Wiltshire, indicates an ore from the Lower Greensand of the district. It was a rich magnetite, fairly pure and not particularly siliceous. Fragments of ore from the same deposits were at Swallowcliffe Down (second century B.C.).⁴

The brown siliceous ironstone called 'Carstone' which occurs in the Folkestone Beds and contains a rather high percentage of iron, may have been exploited in pre-Roman West Sussex, and also in Surrey, since several pieces were found in Hascombe Camp which was abandoned before 50 B.C.⁵

The clay ironstones occurring in shallow beds of nodules near the bottom of the Wadhurst clay were exploited in Sussex in the first century B.C. (Map 1).

In the north bog iron ore provided the main source of supply. There (Somerset), Proceedings of the University of Bristol Speleological Society, vol. 1 (1919–20), p. 15. For Rowberrow Cavern (Somerset) and Round Pound (Kestor, Devonshire), see below pp. 19–21.

² Childe, p. 244.
⁴ Cunningham, loc. cit., p. 53 — R. C. C. Clay, 'An Inhabited Site of La Tène I Date, on Swallowcliffe Down', The Wiltshire Archaeological and Natural History Magazine, vol. xliii, p. 61; Devizes, 1927.
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is definite evidence of bog ores being smelted in the Early Iron Age, e.g. at Wiltrow, Shetland; in Ireland also bog ore was exploited in very ancient times.¹ This ore, being open and porous, was readily reducible and for this reason most suitable for primitive smelting.

Mining Technique

Since the majority of ore deposits in England have outcrops on the surface a primitive method of open-cast mining termed grubbing, sufficed for the needs of the prehistoric era. The ore was simply collected where it cropped out on the slopes of the mountains, or the soil was scraped and the ore-bodies were dug out in hollows or ditches. A very early example of such an open working may have been a ditch along the southern side of an Iron Age camp ascribed to about 200 B.C. and situated at Urswick Stone Walls on the peninsula of Furness in Lancashire.²

It is not impossible that pitting was employed in prehistoric Britain. Some of the numerous mine pits which can be traced in the Wealden area by the round depressions they have left in the soil may be of very early origin. It is probable that they were of the shape of pudding basins, like those dug in the area of Battle in Roman Sussex, and not like the bell pits which were used in the sixteenth and seventeenth centuries.³

Ore Dressing

Iron ores in the natural state are not pure minerals but contain some earthy and stony matter which is termed 'gangue'. A preliminary way of removing the gangue was to wash the ore, but this was done only where the ore was distinctly denser than the adhering gangue. Although there is no direct evidence from earlier than the beginning of the thirteenth century A.D.—from which period some data have been supplied by mining grants in Furness, Lancashire—it is possible that the practice of washing hard ores, an old standard practice in Antiquity, goes back to the Early Iron Age in Britain also. The same applies to the crushing or pounding of hard ores with a hammer, to reduce the bulk to a size suitable for the furnace. Washing and pounding took place at the pit heads to avoid transport difficulties.⁴

The roasting of iron ore which served the purpose of making it porous and reducing moisture, was known in Antiquity. There is, however, no evidence that it was practised in prehistoric Britain. Probably the ore was merely dried by exposure to air. The bog iron ore of the north seems to have received some sort of preliminary

³ See below Chapter XIII.
⁴ Fell, p. 14—Forbes, pp. 51, 384—Straker (p. 19) presumed that ore-dressing such as washing, pounding and roasting was practised in prehistoric Sussex.
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roasting, necessary because of the great amount of moisture it contained. The bog ore stored in a chamber built for the purpose near the smelting-house at Wiltrow, Shetland, may have been dried by artificial heat, since there was a flue on the north side of the chamber.1

Fuel

The fuel used was charcoal made from wood or peat. The wood for charcoal-burning was predominantly oak; birch, hazel and ash were also often used, but charcoal from smaller trees can also be traced, e.g. at Round Pound, Kestor, and at the camp of Sudbrook, in Monmouthshire, near the Severn Tunnel, where ironworking in the first century B.C. is indicated by iron clinker and charcoal; at Rudh'an Dunain, Isle of Skye, and at Crowhurst Park near Battle, in Sussex.2

Charcoal made from peat was used in the north from time immemorial, particularly in Scotland. The peats were cut from the more dense and compact parts of the peat mosses, and then set upright to dry. When thoroughly dried they were stacked for use. The stacks were constructed with the outside peats sloping downwards so that the rain would run off. The dried peats sufficed for use in the kitchen, but for ironworks peat charcoal was generally preferred. It was obtained by charring peats in a deep narrow pit, the mouth of which was nearly covered with wood. At the lower end a small opening was left to admit a small amount of air.3

Pits were not as suitable for charring wood as piles placed above the ground, since they rendered more difficult the regulation of air-supply necessary for charring all parts of the burden equally. Particularly the lower part of the burden sunk in the ground could hardly be exposed sufficiently to the air. As a result, particles of wood and twigs insufficiently coaled are frequently found at the bottom of such pits.

The method of charring described by Aristotle's disciple Theophrastus who lived from 372 to 287 B.C., has remained essentially unaltered; his account is correct even for present conditions and could hardly be improved. He recommended hard-wood and in particular that of young trees, from which the best charcoal is obtained.4

3 PSAS, vol. xxxi, pp. 94–95 — J. H. Dixon, Gairloch, p. 134: Edinburgh, 1886 — At Mid Howe, Orkney, a chamber was discovered which contained a pit 1 foot 8 inches deep, filled with charcoal and ash and situated to the east of a smelting hearth, PSAS, vol. lxviii, p. 476.
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FURNACE AND SMITHY

The type of furnace most commonly used for the smelting of iron in the British Isles from the early beginnings down to the Middle Ages was the so-called bowl furnace. It was nothing more than a shallow pit dug into the ground, in shape resembling a bowl. Bottom and walls were lined with clay, which rendered it possible to remove the slag without each time destroying the walls of the interior. This guaranteed a continued use of the furnace during a series of smeltings, which made iron-production more economical than in an unlined furnace. From this we learn that the first improvement in the development of the primitive furnace had already been achieved when iron-making was introduced into Britain.

The most ancient bowl furnace, actually the oldest iron-smelting furnace in the British Isles, was discovered at Round Pound, near Kestor Rock, Chagford, on the eastern fringe of Dartmoor in Devonshire, in a prehistoric settlement founded some time after 400 B.C.\(^1\) The whole settlement consists of 27 huts. The furnace was in the centre hut of the Round Pound which may have been the chief’s dwelling. Apparently the hut was partly roofless, as an irregular depression or drift pit about 3 feet in diameter and 10 inches deep was discovered in the centre. The hut was divided into two compartments. One, to the left of the entrance, was used as living and sleeping quarters and contained a small hearth for cooking. The other, to the right, served as a workshop. In this two small pits were found.

The furnace was a small clay-lined pit, circular but of irregular shape, 1½ feet at its longest, 10 inches at its widest, and only 6 inches deep. At the time of excavation the cavity was found to be filled with black soil sooty with charcoal, and there was a large mass of iron slag adhering to one side, from haematite ore, which could have come from any of a large number of localities in east Devon. Five stone slabs placed around and close to the furnace mouth may be the remains of a low circular stone wall reinforcing the rim of the mouth. A little more than 1 inch distant from the side on which the mass of slag adhered a slab of granite was found, 5 inches in length and depth, 2 inches wide and rising 2 inches above the ground. A channel 4 inches wide ran between the slab and two smaller stones placed parallel to the slab.

A second pit was found to the right of the bowl furnace, only 2 feet distant. It is of circular shape like the former, but somewhat larger: 1 foot 9 inches in diameter at the mouth and tapering to 1 foot at the base, the total depth being 1 foot 8 inches. At the time of discovery it was filled with ash, sooty soil and charcoal chiefly from oak and a little

\(^1\) Excavated by Lady A. Fox, University College, Exeter, and reported in ‘Excavations at Kestor’, *Tr. of The Devonshire Association for the Advancement of Science, Literature and Art*, vol. 86, pp. 21-62. 1954.
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(a) SECTION

ROOTS OF GRASS AND RUSHES

DARK OCCUPATION SOIL

STONE

SODS

BLACK SOIL SOOTY WITH CHARCOAL

IRON SLAG

FURNACE LINING

12 11 10 9 8 7 6 5 4 3 2 1 0

INCHES'

FEET

(b) PLAN

Fig. 3. Bowl furnace at Round Pound, near Kestor Rock, Devonshire. (a) Section, (b) plan of smelting furnace.

By courtesy of Lady Fox.
hazel, all twigs, the largest diameter of which was 1 inch. No slag was found. The bottom of the pit was reddened by burning.

A similar bowl furnace, of uncertain date but not earlier than of the third century B.C., was at Chelms Coombe Cave near Cheddar, in Somerset. Bottom and walls are packed with slag and the structure has not remained intact. The greatest width was 35 cms. or a fraction less than 1 foot 2 inches. There is evidence of a clay lining inside and also of a clay mantle outside which, although much broken, may be judged to have been about 6 inches thick. Remains of a clay tuyere are present through which the blast was conducted into the furnace.¹ The ore smelted was local haematite.

An early bowl furnace, definitely pre-Roman, perhaps of the second century B.C., was found in a cave at Rowberrow Warren, in Somerset. This was a pit 1 ½ feet deep, with a floor of flat stones, one of which had iron fused on to it. The pit contained charcoal and slag, and in the vicinity abundant slags and haematite with partly reduced iron and with charcoal were found.²

In the same century the smelting of iron was carried out on Swallowcliffe Down, Wiltshire, which is proved by finds of iron slag, charcoal, and one bloom of iron.³

The largest bloom or ingot smelted in a prehistoric furnace in Britain was found at the top of the pre-Roman deposit probably dating from the end of the first century B.C., in the cave of Wookey Hole, Somerset. It seems to have received its shape in a crude and tapering mould which may have been a bowl furnace.⁴

At several prehistoric sites ironmaking is indicated either by slags or a multiple of iron objects, although there is no trace of furnaces; examples are the site at All Cannings Cross, in Wiltshire, inhabited in the fourth century B.C., and the hill-fort of Hunsbury, near Northampton. At Hunsbury there is evidence of ironmaking activity in a settlement which dates back to the fourth century B.C., and which survived well into the first century B.C.—perhaps even longer, though it must have dispersed before the Roman occupation. A remarkably large hoard of iron objects was found here, apparently belonging to the later phase. These objects were found in pits 6 to 7 feet deep, but there is no

¹ See Plate III—The furnace is preserved, exactly as it was found, at Wells Museum, Somerset. See also H. E. Balch, Mendip-Cheddar, its Gorge and Caves, p. 59, second edition. Bristol, 1947—For dating and position within the cave see the Report by the Excavations Committee of the Somerset Archaeological and Natural History Society, 1925–26, pp. 15, 17, 19.
³ Cunnington, loc. cit., p. 53—R. C. C. Clay, 'An Inhabited Site of La Tène I Date, on Swallowcliffe Down', The Wiltshire Archaeological and Natural History Magazine, vol. xxiii, p. 61, Devizes, 1927.

Evidence suggesting smelting is strong, though not conclusive, at the settlement of Hascombe Camp, in Surrey, ascribed to the first century B.C., where the pits with iron slag and, in addition, pieces of brown siliceous ironstone were discovered. The pits may have been bowl-furnaces.\footnote{D. C. Whimster, The Archaeology of Surrey, p. 109. London, 1931 — S. E. Winbolt, Excavations at Hascombe Camp, Godalming, Surrey AC, vol. xi., pp. 86 et seq. — A similar furnace, probably of the first century B.C., was found at Piper’s Cope, near Kirdford, in Sussex, S. E. Winbolt, The Early Iron Age Camp in Piper’s Cope, Kirdford, Sussex AC, vol. lxxvii, pp. 246-247.}

The discovery of iron slag does not of itself prove that iron was extracted intentionally, for it occurs at sites where copper or tin was smelted. At the Caburn, in Sussex, for instance, which was inhabited in the first two centuries B.C., pits containing iron slags were found. The local iron pyrites employed, however, are more suggestive of copper-smelting, and so are the fragments of crucibles some of which were stained green with copper.\footnote{Sussex AC, vol. lxxviii, pp. 13-15.}

From the bottom of a large furnace discovered at the great hill-fortress of Chun Castle, in Cornwall, which was erected between 300 and 250 B.C., a fair amount of slag containing metallic iron was recovered. As the furnace was principally employed for extracting tin, the occurrence of iron-bearing slag has led to the suggestion that tin and iron were smelted alternately. Finds at the prehistoric fort on the Trevelgue promontory near Newquay, in Cornwall, where smelting in cavities cut out of the rock can be traced back to 200 B.C. at least, have cast a different light on the use of iron ore in connection with tin-smelting. An analysis of slag containing almost 60% of iron indicates that the smelters whose task was to slag the siliceous material of the tin ore added iron ores sufficient to combine with the silica to form a slag and so to free the tin. The iron slag found at Chun Castle and at the Caburn was a by-product, and no proof that there was any intention to produce iron.\footnote{E. T. Leeds, ‘Excavations at Chun Castle, in Penrith, Cornwall’, Arch., vol. lxxvi, pp. 216 et seq.; see also the illustrations of the furnace, ibid., Plate i., fig. 3 (facing p. 209), and p. 217, fig. 6 — Gowland, loc. cit., pp. 314-315 — O. H. Hencken, The Archaeology of Cornwall, pp. 126-128. London, 1932 — Evidence relating to Trevelgue kindly supplied by Mr. C. K. Croft Andrew, County Archivist, Northallerton, Yorks.}

Iron slag found in the furnaces of the first century B.C. at the lake-village of Glastonbury, Somerset, also appears to be a by-product, since bronze dross and iron pyrites were present at the sites. Only one of the furnaces may have been used for the smelting of iron. This had the shape of a hollow, flattish basin with an irregular outline; it was 18 inches in diameter, which is only a little larger than the early bowl-
I Two-wheeled chariot, by courtesy of the National Museum of Wales.

II The Capel Garmon firedog, by courtesy of the National Museum of Wales.
III Furnace at Chelms Coombe, Somerset, by courtesy of Professor Palmer, Honorary Curator, Wells Museum.

<table>
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<th>FeO</th>
<th>Fe₂O₃</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>MnO</th>
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</table>

(Analyses by percentage by courtesy of The British Cast Iron Research Association.)

IV (A) Clay tuyere found at Crowhurst Park, East Sussex. Photo kindly supplied by Mr. Sanger, Curator of Bexhill Museum.

(B) Reconstruction of tuyere with clay-capped bellows pipes introduced into the tuyere. The remnants are in the Museum at Bexhill and Lewes in Sussex.
furnaces at Round Pound and Chelms Coombe. The basin was filled with fire-ash and some fragments of iron slag.

Another furnace of uncertain use was found at Saxonbury camp south of Frant, in Sussex. This fortified hill-camp seems to have served in the second and first centuries B.C. and in the first century A.D. as a place of refuge or even as a settlement for miners and ironworkers operating in the neighbouring gills at places such as Colesgrove Wood and Sandyden Gill. The furnace was no more than a pocket in the ground about 4 feet square, shape and dimensions being rather unusual for a prehistoric bowl-furnace. In this pocket a mass of clay 1 foot thick had been laid, on which pieces of charcoal and iron slag were found. As iron was smelted in the above-mentioned gills about a mile distant it appears unlikely that ore was carried for smelting up to the camp which was on a hill 660 feet high. Possibly the use of powdered slag for mixing with the clay for pottery-making explains its presence in the furnace.

The only prehistoric ironworks found in the Weald of Sussex of which remnants were preserved was at Ridge Hill near East Grinstead, in Sussex. In a large heap of slag several completely horizontal layers were discovered which showed distinctly traces of ironworking. Judging by fragments of pottery unearthed there the site had been used in the Roman period from the end of the first century to about 300 A.D.; but at a greater depth pre-Roman pottery was discovered in the slag which indicates that iron was worked at the site by Celts prior to the Roman era. The working area differed from all the bowl-furnaces mentioned above. It was a completely flat hearth, circular in shape but of much larger dimensions than any of the others; about 8½ to 9 feet in diameter. The top layer was constructed of stones embedded in sand, horizontal and without any depression in which the iron could collect. Such a structure could not be used for smelting. As no ore was found, but only sand burnt red, charcoal dust and slag, there is nothing to suggest that it was used for ore-roasting either. The most probable explanation is that it was the platform of a smithy in which the blooms obtained from a furnace now lost were consolidated and forged into implements for the use of the agricultural population in the vicinity.

A working area even larger was found at Loanhead of Daviot, in Aberdeenshire. The area over which the soil was burnt bright red was 22 by 13½ feet. Charcoal was scattered all over the place, but occurred in the greatest quantity round about a group of stones on the north-east side. The stones were carefully placed in a circle with an opening to the west. In between them and on them numerous large and small pieces of iron slag were scattered, together with charcoal. The interior was

1 Bulleid, loc. cit., pp. 166, Fig. 38, and 391.
2 S. E. Winbolt, Excavations at Saxonbury Camp, Sussex AC, vol. lxxi, pp. 228-231—See also Map I.
D—H.I.S.
Prehistoric Ironworking

full of fragments of charcoal and black slag. Apparently this was a small bowl-furnace in which the ore was smelted, while the bloom obtained was worked up in the wider area.¹

A whole iron-plant, almost complete though much damaged, was discovered at Wiltrow, Shetland.² Although the date is uncertain, occupation of the site took place very early in Shetland’s Iron Age. The smelting-house was an elliptical stone building. On the northern side three furnaces had been constructed, but their dimensions cannot now be determined. The air blast was conducted through flues, and a chamber measuring 6 by 7½ feet behind the flues may have served for storing charcoal obtained from peat, since the floor of the chamber was covered with peat ash. On the south wall of the smelting-house an opening led into a passage and through it into another chamber which evidently served as an ore bunker, since a considerable quantity of bog iron ore was found in it. It may also have been used for roasting bog ore, as there was another flue on its north side. Some 10 feet to the north was the dwelling of the ironworkers: an elliptical building measuring 31 by 25 feet over all.

One essential part of the equipment of a prehistoric ironworks is missing at Wiltrow. No vestiges of a workbench for forging the bloom have been found among the debris. In this respect the remains of a smithy discovered in a cave on the west coast of the Isle of Skye and

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Fig 4. One vertical slab (L), and one horizontal slab (M) set at its foot, form the back of the furnace; the side walls are represented by blocks set on edge (N and P), which do not reach fully up to the back of the furnace; between these 2 stones a smaller block (Q) fills up most of the front. Smaller blocks lay on the south end of M and the east end of P.

(A) Plan of Rudh’a’n Dunain Cave. From Plate III, PSAS, vol. lxxxvi, facing p. 222.
(B) Section of Cave. From Plate IV, ibid.

shown in Fig. 4 supply supplementary evidence, although the whole plant was much smaller.

The works was operated in the early centuries of the present era,¹ but it may possibly date back to the first century B.C. It was equipped with a small bowl-furnace the sides of which were built up with stone slabs set in soft peaty earth and packed outside with a covering of sand. Fragments of clay found may indicate a clay lining. The dimensions of the pit do not seem to differ much from those of the furnaces of earlier centuries. They cannot, however, be ascertained exactly on account of the ruined state of the pit. Bellows must have been used, because in a cave like this there would have been too much back-draught if the blast had been produced by a natural draught. Of particular interest are the two stone slabs on the floor level in the rear of the smelting pit, one of which is placed horizontally, the other vertically. They clearly form a platform or working bench on which the bloom lifted from the furnace was consolidated by hammering. Slag was found all around the furnace and the bench. The whole plant apparently constituted an ironworks on a small scale, in which every stage from ore to finished product was conducted. Iron was smelted from the ore and worked into wrought-iron bars, from which small articles such as hooks, knives, nails, etc., were forged to satisfy the demands of settlers in the vicinity.

THE PROCESS

The process was conducted in two consecutive but closely connected stages. In the first, which is usually termed ‘smelting’ although the iron was never reduced to a liquid state, the reduction of the ore to the metallic state was achieved. In the second stage the product obtained from the furnace was consolidated by forging.

As a preparation for the actual smelting process the clay lining of the furnace was hardened to resist the action of the blast. This was effected by pounding the clay of the lining and hardening it by burning a considerable quantity of charcoal inside the furnace. When the lining was supposed to be hard enough, more charcoal was added. Upon this a mixture consisting of small pieces of ore and charcoal was laid, and then alternate layers of charcoal and layers of ore embedded in charcoal, until several strata were piled up, the top layer being charcoal only. Finally the pile, which rose above the cavity of the furnace, was covered with small charcoal pounded firm.

When the pile was completed, fire was introduced through the tuyere or flue. First a gentle blast was produced to expel the hydroscopic water contained in the ore. When sufficient water was thought to have been

¹ The date is suggested as a safe one by Mr. Stevenson, Keeper of the Museum of Antiquities, Edinburgh — See also PSAS, vol. lxvii, pp. 207-219, and V. G. Childe, The Prehistory of Scotland, loc. cit., p. 226.
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expelled, a stronger blast was turned on, and the heat increased. The oxygen blown in combined with the carbon of the incandescent charcoal thus being converted into carbon monoxide (CO), a ‘reducing’ gas. The gas in its ascent combined with the oxygen of the ore to produce the chemical change which reduces ore to its metallic stage. Reduction took place at a temperature in the region of 1200°C. At such a temperature, which is low compared with the melting point of iron (1528°C), only a partial reduction is effected. The iron is not liquified, but separates into tiny crystals, of which several soon begin to unite in the slag into small bodies, porous, spongy and intermingled with particles of slag. These metallic bodies gradually increasing in volume finally conglomerate into a larger mass, the ‘bloom’, which is extracted from the furnace with tongs.¹

Iron ores are not only combined with oxygen, but are also contaminated with an unwanted earthy or stony material termed ‘gangue’, the principal constituent of which is silica.

During the process of smelting, the silica of the gangue separates, and it combines with a part of the ferrous oxide contained in the ore to produce a fusible silicate or slag, the formation of which is promoted by the alkalies of charcoal ash. At the relatively low temperature generated in the direct process a considerable proportion of ferrous oxide which is either not at all or not completely reduced always remains in the slag. The resultant ferro silicate protects the iron from carburisation. It also acts upon phosphorus which is present in the majority of British ores, particularly in the bog ores extensively mined in prehistoric Scotland and Ireland. Phosphorus is an objectionable element, since it makes the iron brittle when cold, a state termed ‘cold shortness’ by which the malleability is greatly impaired. The higher the content of ferrous oxide in the slag, the more phosphorus will pass into it. Sulphur which tends to weaken the iron when hot (‘hot shortness’) was present only in small proportions in the ores. It could be removed either by weathering the ore, or by allowing the manganese oxide, present in many of the ores employed in early Britain, to act as a desulphuriser.

The iron produced was generally of very good quality, comparatively free from damaging impurities (App. I). The purity, however, was achieved by an excessive waste of charcoal and ore. Generally 50 to 58% of iron in the ferrous state was lost in the slag, but the waste was of little account since ore and wood for charcoal were abundant.

The flue of the furnace at Round Pound, the earliest discovered in Britain (Fig. 3), as well as the clay tuyere at Chelms Coombe (Pl. III) were placed above ground level, so that the slag bath was deep enough to protect the uniting crystals of iron from the action of the blast. The slags at Chelms Coombe (Pl. III) are of three different kinds. Sample 1

¹ Neumann, pp. 12, 29, 49–47 (with illustrations showing growth of crystals and formation of the bloom, Bild 22–28).
Prehistoric Ironworking

is a slag concreted on the clay lining of the furnace interior, parts of which are in the slag (visible as white-coloured particles). Sample 3 is a partially reduced (roasted) ore from the upper layer of the pile, which is shown by the high percentage of combined water (H₂O) not yet driven off. Sample 2 is from a lower layer and contains less hydroscopic water and a greater proportion of ferrous oxide (FeO) than 3. The contents of titanium (TiO₂) and manganese (MnO) made the ore particularly suitable for the production of steel.

Blast air for generating the temperature required for smelting was produced either by natural or by artificial draught. Blast production by natural draught is shown by the flues found at Wiltrow, in Shetland. The flue which was in the best state of preservation when discovered was a narrow stone channel some 5 to 6 inches wide, and 4 feet long from the outer end at which the wind entered, to the furnace. At 1 foot 9 inches from the outer end a flat triangular stone, which fitted into a slot on either side of the channel, evidently served as a shutter to put the flue out of action.¹ Remnants of a stone channel found at Round Pound, Kestor, at the side of the furnace (Fig. 3) may be indicative of a similar flue. A flue had one distinct advantage: the air conducted through the flue received some pre-heating from the incandescent coal and the liquid slag before it entered the furnace.

Artificial blast production with the aid of bellows appeared to be employed in the pre-Christian era side by side with the use of natural draught. At Rudh’an Dunain Cave on the Isle of Skye, no other means of heat generation was possible, since efficient blast production by natural draught would have been rendered impossible by the back draught in the cave.² Bellows with clay-protected nozzles were used by the smiths at Glastonbury in the first century B.C.³ The earliest evidence discovered is a clay tuyere inserted into the wall of the third-century bowl furnace at Chelms Coombe Cave (Pl. III). Only the tuyere was found, but no traces of bellows. Since the smallest internal diameter of the tuyere hole (three-quarters of an inch) is the same as that of the hole of a tuyere found at Crowhurst in Sussex where iron was already being smelted before the Romans came (Map I, No. 9), it seems justifiable to presume that the same appliances were used for blast production at both places. At Crowhurst not only clay tuyeres but also clay pipes suggesting a pair of bellows were found amongst the debris (see Plate IV).

The trumpet-shaped tuyeres (Pl. IV) were of hard-baked yellowish clay. With them lumps of clay much intermixed with slag were found. The lumps had twin holes converging towards their orifices, which were close together. The twin holes are evidently remnants of the clay

² See above p. 25 note 1.
³ Childe, p. 237.
nozzles of a pair of bellows for forcing blast air through the tuyere into the furnace (Pl. IV). The tuyere fixed in the wall of the furnace not only served as an air-conductor, but also protected the nozzles of the bellows from destruction by the fire.

The product obtained by reduction was not fit for immediate use, since the bloom of iron was mixed with slag. When smelting had finished, the bloom was extracted with iron tongs, after which it was immediately sprinkled with water to facilitate the removal of slag from the surface by careful beating with a sledge hammer—the drip pit in the centre of the hut at Kestor would have been sufficient to supply the quantity of water required. After this the iron was re-heated and hammered.

The Celtic smiths in Britain used very simple tools. Polished stone hammers and stone anvils hardly distinguishable from hammers were found at various sites such as Round Pound, Kestor (fourth century), and at Wiltrow, Shetland (around b.c.).\(^1\) The anvil stone at Kestor was made of a fine-grained granite boulder. It was broken at the base but it appears to have had a stump foot by which it was held upright in the ground. It was used for forging, as well as for smoothing and sharpening implements.\(^2\) Hammer and anvil are shown in Plate \(V\), a and b.

Hammering the bloom was not such a tedious and laborious process as has often been presumed. Since the bloom was very small, it could easily be handled, and the tongs used were quite adequate for the purpose. A pair of early tongs was amongst the finds of Llyn Cerrig, Anglesey, dating from the second or early first century b.c. (Pl. VI). The overall length was \(21\frac{1}{4}\) inches. The handles were rounded in section becoming rectangular towards the jaws. One handle was shorter than the other and curved inwards, so as to facilitate the slipping-on of an oval-shaped iron ring which enabled the ironworker to hold his object firm during hammering. This type of tong was a tool standardised in the Early Iron Age, and it has remained in use, essentially unaltered, ever since.\(^3\)

Hammering required red heat (850–900 °C) which was obtained by intermittent re-heating, either in the same furnace which had been used for smelting, or in a separate furnace. There is no evidence of a separate furnace having been used in pre-Christian Britain. By hammering, slags were removed, the pores of the iron were closed, and the texture was changed to that of a coherent metal. A complete separation of slag from metal, however, was not achieved, nor an iron uniform in composition. Bands of iron varying in composition from wrought iron to mild steel alternated with one another.

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\(^1\) See above p. 25, note 1.
\(^2\) Fox, pp. 41 and 96.
\(^3\) A. Fox, loc. cit., pp. 56–57.
STEELMAKING

The soft and ductile wrought iron, mostly containing very much less than 0.1% of carbon, though suitable for various articles of use, was not hard enough for cutting implements and weapons, since cutting edges produced only by heating and hammering became blunt very quickly. Only steel which contained a higher percentage of carbon had the hardness which alone made iron superior to bronze.

Steel was produced in different ways in the prehistoric era, either by producing what was termed ‘natural’ steel directly from manganese-bearing iron ores, or by surface-carburisation of wrought iron.

The method of producing steel directly from suitable ores, those containing manganese and being comparatively free from damaging impurities such as phosphorus, arsenic and sulphur, was probably discovered around 500 B.C. by Celtic tribes living in the Austrian Alps, which later constituted the Roman province of Noricum. A special method had to be employed, quite different from the method for producing soft wrought iron. The furnace was pre-heated for several days. For smelting the ore a greater quantity of charcoal—preferably from oak, which generated greater heat—was charged and a smaller quantity of ore. At the higher temperature generated, the metal which separated from the slag was retained longer in contact with the incandescent charcoal, whereby a higher degree of carburisation was achieved. The tuyere was set nearer to the horizontal to prevent the air blast from penetrating to the core of the metal and burning out the carbon.

Steel could be produced by this method from any of the ores employed for smelting in the primitive furnace, but at the expense of the quality of the product. Steel of better quality was only obtained from smelting manganese-bearing ores comparatively free from impurities. Manganese makes the metal more readily hardenable.

The earliest instance of manganese-bearing ores being smelted in Britain is shown by the slag from the furnace at Chelms Coombe Cave, Somerset, which probably dates back to the third century B.C. The content of manganese and, in addition, of titanium made the ore most suitable for the production of steel. Unfortunately no products made from the ore were to be found. The earliest which have been discovered in Britain are segments of wheel-tyres found at Llyn Cerrig Bach, in Anglesey, and dated to a period approximately between 150 B.C. and A.D. 50. The carbon content of the material varies from 0.74% to

2 Neumann, p. 55.
3 See Plate III, analyses.
4 Fox, pp. 12, 60, 75-76 — Analysis, App. I.
by which it is characterised as a high carbon steel. Although
the carbon content is variable throughout the mass there is no evidence
of gradation through the thickness, which certainly would be present if
the material had originally been a wrought-iron bar converted into
steel by surface-carburisation. Each of the layers from which the tyre
was made is a true steel and differs from its neighbours only slightly
in carbon content. Slag is present in a few stringers only, which is in
keeping with the low content of silicon. The origin of the wheel-tyres
cannot be determined, nor is it possible to locate the ore from which
they were made. Ores of a purity sufficiently high to be possible bases
for the production of the kind of steel from which the tyres were made,
are, though scarce in quantity, fairly widespread.

The second method is known as the cementation process, in which
wrought iron was converted into steel by causing it to absorb carbon
through contact with carbonaceous matter at red heat. Most of the
ancient steel was produced by this process, which probably evolved from
the repeated heating in charcoal between the hammerings required for
converting the crude bloom into a wrought-iron bar. If the same
method which was applied for producing steel from the ore was care-
fully observed, the wrought iron could be carburised at or near the
surface. The depth of the superficial carburisation depended upon the
temperature and the time during which the iron remained in contact
with the carbon of the incandescent charcoal.

The second pit at Round Pound, Kestor, may have been used for
surface-carburisation of iron extracted from the furnace. The assump-
tion that it served as a hearth for reheating the iron for the hammer, by
which slag was extruded and the iron was consolidated, cannot be
maintained, since not the slightest particle of slag was found in the pit.
Small particles of slag and even of iron would have been bound to fall
off from the surface if, after the hammering and loosening of the slag,
it was again reheated. The larger dimensions which rendered it
possible to charge a greater quantity of charcoal such as was required
for carburising also indicate use for this purpose. If we are really
justified in believing that it was so used, the second pit at Round Pound
is the most ancient cementation furnace in Britain.

Carburisation was not the final stage in the production of steel. To
give the carburised and solidified product the desired degree of hardness,
a heat treatment called 'quenching' was applied. Quenching was known
in Antiquity at least since 1200 B.C. It was a rapid cooling process,
achieved by plunging the steel at a high temperature into water, which
made it very hard, but also very brittle. To reduce the brittleness
without impairing the hardness a further heat treatment called 'tem-

1 Forbes, p. 411.
2 See above p. 19.
pering' was applied, but there is no evidence of its use in Britain earlier than in the Roman era.  

The production of steel was an elaborate process. It made steel an expensive product which for this reason was used sparingly. A way of preventing waste of the costly material was 'steeling', which was very much used in the Middle Ages, and later still, in the manufacture of cutting implements and weapons. It was achieved either by partial carburisation, of which however there is no evidence from prehistoric Britain, or by welding a strip of steel on to a wrought-iron object, which method seems to have been used in Britain before the Romans came. This is indicated by two curious articles discovered at the Roman fort of Newstead, in Scotland. Apparently they were used as picks and were made, like modern picks, by welding together two parallel strips of iron. They are slightly curved, each measuring 23 inches in length. At either end they are flattened to an edge which is about 1 ½ inches deep. The edges seem to have had steel let into them. One of the edges had been twisted in the fire, and in both of them the hammer-strokes are visible near the points, which signifies poor workmanship.

Although the implements show signs of wear, neither of them has an eye for the insertion of a shaft. They could be used only by being grasped in the hand or fastened to a forked stick. As the Roman smith was very familiar with the operation of making an eye, the implements would appear to have been made by a Caledonian smith unacquainted with Roman workmanship.  

Steel had the same deficiencies as iron. Since both were obtained in a spongy state, they were heterogeneous in composition showing varying carbon contents and as a result different degrees of hardness within the same piece of iron or steel. Worse than the inequality in composition was a certain impurity of the material caused by the considerable inclusions of slag. Such defects remained characteristic of the steel produced in Britain more or less until in 1740 B. Huntsman invented cast steel which was homogeneous in composition.

MECHANICAL WORKING PROCESSES

The crude bloom produced in the furnace, and thus also the hammered bloom or bar, were too small to be forged into any object of a large size. To produce larger pieces of iron a number of single bars were piled, forged and welded together in a charcoal fire. A currency bar, e.g., which was found at Llyn Cerrig, Isle of Anglesey, and dated to the first century B.C., had been built up of three pieces welded together, although it weighed less than 2 lb. The welds at the tips are clearly visible.  

1 The structure in the quenched condition is called 'martensite' — For tempering see below p. 57.
3 Fox, pp. 41 and 85, illustration Plate xxx, No. 61.
Methods used to unite and fasten together separate pieces of iron were riveting and welding.

For riveting, gripping-tongs were used, a pair of which, dating from a period between 150 and 50 B.C., was found at Llyn Cerrig, in Anglesey. It was some 8 inches long and served to hold thin metal plates firmly for riveting. At the same locality a square-sectioned bar was discovered, one end of which was evidently riveted on to another metal object.1

The earliest object found in Britain with traces of welding on iron is a socketed iron sickle from Llyn Fawr, in Glamorgan, assigned to the sixth century B.C.2 The plate from which the socket was rolled meets in a vertical seam beneath the blade. The socket is held in shape by a grooved iron ring which is welded on to its lower end. The base of the socket extends slightly below the ring, hammered back to hold it in position.

Striking evidence of the skill of the smith in prehistoric Britain is supplied by chain-links found at Llyn Cerrig, Anglesey. They are ascribed to the first half of the first century B.C. and were presumably made in Eastern England, whence they were taken to Anglesey by an old trade route across the Midlands by Charnwood Forest and Cannock Chase. Macro-examination of one of the links proved that it was made from two roughly forged slabs of wrought iron placed one on top of the other, then forged to shape and bent. Afterwards the ends were scarfed and welded together. The most interesting feature is the closing of the central portions of the link until they met forming a figure-of-eight link. This had been done with a hammer, and apparently with internal dies, as is indicated by a distinct flattening on the inside of the finished link.

![Diagram](image)

**Fig. 5.** Forming a figure-of-eight link for a chain. *Top,* link not closed but with dies placed inside; *bottom,* link closed. Sketch by Mr. R. J. Richardson, of Messrs. Brown, Lenox and Co., Pontypridd.

By courtesy of the National Museum of Wales.

1 Fox, pp. 41–2, 96, Plates vi and xix (tongs).
2 Illustrations: *Arch.*, vol. lxxi, p. 196, Fig. 2.
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The die next to the link made previously would have the shape of a horse-shoe, while on the outer end a plain die or a bar would have been used. The link is very similar to a modern stud link of the type produced for use on ships and formerly thought to have been unknown before the nineteenth century. This form of link increased the load a chain is able to carry without distortion. It also prevented the chain from becoming twisted and entangled when it was used. The same technique was employed by contemporary Celtic smiths in France, and was still used by the smiths of Roman Britain.¹

OUTPUT

Blooms or ingots of crude iron from the prehistoric period are very rare. The few preserved are extremely small. The largest discovered at Wookey Hole Cave, in Somerset, had a weight of a little less than 7 lb.²

It is not possible to make even an approximate estimate of the daily output and the yield of iron in prehistoric Britain. It is unlikely that more than one smelting took place anywhere within a day. Accordingly the output in twenty-four hours would not be more than about 10 lb. as a maximum which tallies with the maximum weight of the blooms found (about 7 lb.). Possibly the output increased in the course of time, when it became possible to build slightly larger furnaces.

Production generally was on a small scale and carried on to meet local requirements only. The size of hoards of so-called currency bars,³ however, seems to indicate a production larger than what was required for local needs. It suggests that by the first century B.C., if not earlier, iron was produced to some extent commercially, although not enough for it to be likely that any was exported.

¹ Fox, pp. 38 and 84 — Analysis of the iron, App. I — The chain is in the National Museum of Wales at Cardiff.
² Preserved at the Museum of Wells, Somerset, measuring 5 by 3 by 2 inches — The most ancient bloom discovered in Britain was found among the finds at Swallowcliffe Down, Wiltshire, which date from between 500 and 150 B.C.; the weight of the bloom is between 1 and 2 lb. Evidence kindly supplied by Professor C. F. C. Hawkes, Oxford, and N. Thomas, M.A., Curator of the Museum at Devizes, in which the bloom is preserved — Production of one bloom per day continued throughout the Middle Ages, see Chapter 8.
³ 394 from Meon Hill, and c. 140 from Salmonsbury Camp, Gloucestershire, and two hoards of 150 each from Malvern, Worcestershire,
CHAPTER III

THE IRON INDUSTRY IN
ROMAN BRITAIN

REGIONAL DISTRIBUTION

THE first attempt to subjugate Britain was made by Caesar, but his expedition in 55 B.C. was a failure and the second made in the following year had no permanent result either. The actual occupation of Britain by the Romans began in A.D. 43, when a Roman army landed on the coast of Kent and subsequently occupied south-east and central England. It took longer to conquer Wales and the mountainous region of the north of England. In 78 B.C. the last resistance in Wales was crushed, and two years later a Roman army was led for the first time into the Scottish Lowlands. The Highlands, however, were never reached, and the Romans withdrew even from the Lowlands about sixty years later. In A.D. 123 the northern frontier of the new Roman province was fixed between the Tyne and the Solway by building a wall—‘Hadrian’s wall’—remnants of which are still in existence. The Romans never penetrated into Ireland. Cornwall and Devonshire remained almost completely outside the sphere of Roman influence, to judge by the paucity of Roman remains discovered in the area.

According to the Roman historian Tacitus one of the attractions which prompted the invasion of Britain was the mineral wealth of the country. The hopes of the invaders were mainly centred on the expectation of considerable gain from mining the precious metals such as gold and silver which they hoped to find, and also lead. They found no gold, and little silver, but abundance of lead. In consequence, the exploitation and utilisation of lead ore developed vigorously in England and Wales under the Romans. Iron, although not considered a valuable metal, was needed for the maintenance of the garrisons and the expansion of agriculture and crafts. Consequently an increase in iron-production became part of the ‘production drive’ which evolved to its fullest extent in the third and fourth centuries.
The two principal iron-working regions in Roman Britain were in the southern half of England: Sussex, and the area of the Forest of Dean in Gloucestershire, which latter extended into the adjacent parts of Herefordshire, Monmouthshire, and South Wales.

In the first two centuries of the Roman era the production of iron was very much greater in Sussex than in the western counties. The extension of the iron-working area is shown on Map I, comprising the localities for which archaeological evidence is available. It is not impossible, however, that more will yet be discovered in the numerous slag heaps distributed all over the area.

Of the fourteen Celtic ironworks which the Romans found in the Weald of Sussex, Surrey and Kent, they continued to work six; three of them over a period extending into the second century of our era. These were Bardown near Ticehurst, Crowhurst Park north of Hastings, and Ridge Hill near East Grinstead. All six ironworks were in Sussex. The two pre-Roman works in Surrey and the one in Kent were abandoned. Despite the initial contraction of the working area, under the Roman dispensation more iron was soon being produced and worked than was before. Twelve of the eighteen ironworks operated in the Roman era in Sussex were newly established in this period (for the following see Map I).

MAP I. Prehistoric, Roman and Medieval Ironworks in the Weald.
<table>
<thead>
<tr>
<th>No. on map</th>
<th>Place Name</th>
<th>Parish and County</th>
<th>Date</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bardown</td>
<td>Ticehurst, Sx.</td>
<td>1st cent. b.c.</td>
<td>1302-1433</td>
</tr>
<tr>
<td>2</td>
<td>? Barnehorne</td>
<td>Bexhill, Sx.</td>
<td>—</td>
<td>1306</td>
</tr>
<tr>
<td>3</td>
<td>Beaufort Park</td>
<td>Westfield &amp; Battle, Sx.</td>
<td>from A.D. 98 to about 140 probably 2nd &amp; 3rd cent. perhaps 1st &amp; 2nd cent.</td>
<td>—</td>
</tr>
<tr>
<td>4</td>
<td>Chiddingly</td>
<td>Chiddingly, Sx.</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>5</td>
<td>near Chitcombe</td>
<td>Brede, Sx.</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>Carr's Wood</td>
<td>Maresfield, Sx.</td>
<td>1st cent. b.c.</td>
<td>—</td>
</tr>
<tr>
<td>7</td>
<td>Colegrove Wood</td>
<td>Rotherfield, Frant Sx.</td>
<td>1st cent. b.c. &amp; Roman period</td>
<td>—</td>
</tr>
<tr>
<td>8</td>
<td>Colliers Green</td>
<td>Ewhurst, Sx.</td>
<td>Shortly before A.D. 43 to about 140 pre-Roman slag</td>
<td>—</td>
</tr>
<tr>
<td>9</td>
<td>Crowhurst Park</td>
<td>Crowhurst, Sx.</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>10</td>
<td>Crow's Nest</td>
<td>Maresfield, Sx.</td>
<td>1st cent. b.c.</td>
<td>—</td>
</tr>
<tr>
<td>11</td>
<td>Dallington (Cinderhill, or Herrings)</td>
<td>Dallington, Sx.</td>
<td>late medieval</td>
<td>—</td>
</tr>
<tr>
<td>12</td>
<td>Dry Hill Camp Footlands</td>
<td>Lingfield, Sy.</td>
<td>before A.D. 43</td>
<td>—</td>
</tr>
<tr>
<td>13</td>
<td>Footlands</td>
<td>Sedgescombe, Sx.</td>
<td>about A.D. 50-400</td>
<td>—</td>
</tr>
<tr>
<td>14</td>
<td>Forewood</td>
<td>Crowhurst, Sx.</td>
<td>—</td>
<td>extensive bloomery</td>
</tr>
<tr>
<td>15</td>
<td>Hascombe Camp</td>
<td>Godalming, Sy.</td>
<td>2nd &amp; early 1st cent. b.c. pre-Roman slag</td>
<td>—</td>
</tr>
<tr>
<td>16</td>
<td>Hempsted Herrings, see Dallington</td>
<td>Benenden, Kent</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>17</td>
<td>Icklesham</td>
<td>Icklesham, Sx.</td>
<td>Roman bloomery 4th &amp; 5th cent. A.D.</td>
<td>—</td>
</tr>
<tr>
<td>18</td>
<td>Nanny's Croft</td>
<td>Arundel, Sx.</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>No. on map</td>
<td>Place Name</td>
<td>Parish and County</td>
<td>Date</td>
<td>Reference</td>
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<tr>
<td>-----------</td>
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</tr>
<tr>
<td>20</td>
<td>Oaklands</td>
<td>Westfield, Sx.</td>
<td>—</td>
<td>1st half of 2nd cent. A.D.</td>
</tr>
<tr>
<td>24</td>
<td>Playsden</td>
<td>Rye, Sx.</td>
<td>pre-Roman</td>
<td>—</td>
</tr>
<tr>
<td>25</td>
<td>? Potmans ('hamer-wyse')</td>
<td>Catsfield, Sx.</td>
<td>undated (about 1336)</td>
<td>—</td>
</tr>
<tr>
<td>27</td>
<td>Roffey</td>
<td>Horsham, Sx.</td>
<td>—</td>
<td>1318, 1327</td>
</tr>
<tr>
<td>28</td>
<td>Roman Gate</td>
<td>Slinford, Sx.</td>
<td>pre-Roman</td>
<td>&amp; early Roman slag</td>
</tr>
<tr>
<td>32</td>
<td>Wadhurst (perhaps Wenbons bloomery)</td>
<td>Wadhurst, Sx.</td>
<td>—</td>
<td>1318</td>
</tr>
<tr>
<td>34</td>
<td>Westfield</td>
<td>Westfield, Sx.</td>
<td>—</td>
<td>Date indefinite (Roman coins amongalag)</td>
</tr>
</tbody>
</table>
The centres of the iron industry in Roman Sussex may be divided into three. The most important was in the coastal region north of Hastings. Exactly one half of the eighteen ironworks which are definitely known to have been operated under the Romans were situated in the neighbourhood of Hastings. The two works which were apparently the most important ones in Roman Sussex belong to this group. They were at Beaufort Park, roughly between Hastings and Battle, and Footlands, a little north of Sedlescombe. Footlands was worked throughout the whole of the Roman era. The second centre was less concentrated. It extended from Chiddingly in the south to Maresfield in the west, and to Colegrove Wood and Bardown in the north. This group consisted of five works of which Oldlands, a little to the north of Maresfield, seems to have been the only one of major importance and the only one to function for a long period. The third centre containing four ironworks was even more scattered, extending from East Grinstead in the north, over the west of Sussex to Slindon and Arundel in the west and south.

Judging by the geographical distribution of the Roman ironworks in Sussex, there was a tendency towards concentrating more in the south-east corner of Sussex, which was nearer to the coast. The industrial area in the neighbourhood of Hastings appears to have been a creation of the Romans, since all the nine works operated in the district are dated to the Roman era. According to archaeological evidence the one exception, the bloomery at Crowhurst Park, was erected just before the Romans arrived.

In the western region the iron industry under the Romans seems to have developed later than in Sussex, but when it had started, this area became of primary importance.

Although much evidence has been lost through the re-smelting of large amounts of slag in later centuries, ironworking seems to have been carried on in the Forest of Dean from the second to the fourth century. Smelting of iron extended far beyond the forest into Herefordshire, Monmouthshire and Wales, and possibly also as far as West Somersetshire. Some Roman coins have been found under the refuse of haematite mines at Luxborough, on the Brendon hills, and at Luccombe near Exmoor.

The greatest activity was apparently in the south-east corner of Herefordshire. Nearly the whole area is covered with beds of slag which in some places are from 12 to 20 feet thick. The amount of Roman coins and pottery found in them shows beyond doubt that at least a part was

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1 A further bloomery indicated by a bed of slag at Pepperidge-Eye, south of Battle, can hardly be ascribed to the Roman period, since the only evidence discovered was a small fragment of Samian pottery, Straker, p. 351.
2 Arch. J., vol. 131, pp. 38–39. Despite the Roman coins evidence is not completely convincing, since an iron mill called Horner Mill in the parish of Luccombe was erected about 1600 and still worked in 1610, PRO, Chamber Proceedings Jas. I, E 3/31; VCH, Somerset, vol. ii, p. 392. The coins may have been dumped with refuse from later smelting.
V (A) hammer stone; (B) anvil stone. From Transactions of the Devonshire Association for the Advancement of Science, Vol. 86 (1954), 10 (b) and 11 (b).
VI

(A) grippers-tongs; (B) forging-tong. From Fox, Plate VI, 131.
refuse from Roman iron-smelting, even though we know that ironworking continued in this region in the Middle Ages and still later. The manufacturing centre of the area was presumably near the Roman military station of Ariconium, the site of which is at Bollitree, in the parish of Weston-under-Penyard, about 3 miles east of Ross-on-Wye.  

Although the beginning of iron-smelting cannot be dated, it is unlikely that the surface-ore deposits in the nearby Forest of Dean would not have been noticed and exploited by the native Silures before the arrival of the Romans. The Wigpool Mine, which is about 2½ miles distant, was probably one of the mines from which the raw material was obtained. The Romans, with the help of native labour, soon began iron-smelting at and near Ariconium. A rapid development took place about 250 A.D., and the industry reached its height in the era of Constantine the Great, Emperor from 307–337 A.D., but declined after 360. It seems, however, to have continued until the end of the Roman era in Britain. The slope of the ground on the western side of Ariconium consists of an immense mass of iron slag: hence the name of 'Cinderhill' still applied to it. It was mainly this mass of cinders which earned the place the reputation of having been a 'Merthyr Tydfil of the Romans'.

In Glamorgan many traces of iron-working have been discovered, in particular at Ely near Cardiff, and in the district surrounding Llantrisant and Miskin. Even in Carnarvon, Denbighshire, and on the Isle of Anglesey, in North Wales, slag and traces of working have been discovered at many sites of Roman date.

Mining and working of iron was extended to the Midlands. As regards Worcestershire, evidence is scanty and not completely convincing. In the low riverside area of Worcester called Pitchcroft which is now occupied by the racecourse, a great quantity of iron slag was discovered in the eighteenth century which may be indicative of local iron-smelting. At Droitwich also, slag was found in a Roman building which had been occupied during the third and fourth centuries A.D. which is suggested by finds of pottery and coins. This might indicate the manufacture of iron on a small scale. Similar slag was discovered in the filling of the ditch of the Roman fort at Dodderhill near Droitwich, which protected a minor military road.

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1 G. H. Jack, 'Excavations on the Site of Ariconium', Woolhope Tr., Hereford, 1924, in particular pp. 1–2, 26–31, Plate 16 (facing p. 47); a map showing the parishes in South Herefordshire, where iron slags and clinkers have been discovered — Arch. J., vol. xxxiv, p. 364 — VCH, Hereford, vol. 1, p. 171 — Davies, pp. 152–153.


4 VCH, Worcestershire, vol. 1, p. 203; possibly, it was the place where in the late seventeenth century Andrew Yarranton found 'the hearth of a Roman footblast' and took 'many thousand tons' of slag.


E—H.I.S.

39
The Iron Industry in Roman Britain

Within the boundary of Stratford-upon-Avon in Warwickshire, near the main road to Tiddington, an industrial settlement existed throughout the whole period of the Roman occupation. Remnants of an iron-furnace and a hearth for roasting ore were discovered, but it is impossible to say whether local ores were being used, or, if so, whence they were obtained. Possibly they came from Walsall, in Staffordshire, which supplied high-quality ore in the Middle Ages and even later.¹

The Romans appear to have opened a mining field hitherto not exploited in the area of Rockingham Forest and extending towards the River Nen, in Nottinghamshire. Considerable amounts of charcoal and iron slag indicate smelting of haematite ore. The iron produced was probably used for armament and implements in the minor military stations erected by the Romans at short intervals along the River Nen and farther westward.²

Another new industrial area was created in the north-west of England. The need for iron for the Roman army in Britain stimulated production wherever forts and fortresses were erected. All along the fortified frontier in the north British smiths established their working places, in which they produced iron for the needs of the garrison. At more important places complete industrial settlements were set up, e.g. at Wilderspool near Warrington on the border of Cheshire and Lancashire adjacent to a military station, which protected the crossing of the River Mersey and an important junction of Roman roads from Chester, Manchester, and Wigan. The Romano-British settlement which adjoined the military station covered an area of approximately 16 acres. From the first to the fourth century of our era it was the seat of considerable industrial activity such as pottery, glass-making and all kinds of metal working including the production of iron. Smelting sites from the Roman era have been discovered near Scunthorpe, Lincolnshire, and in Norfolk.³

Transport of iron was greatly facilitated by the Roman road-system.

ROAD-SYSTEM AND TRADE

The waste products of ironworks such as slag or cinder were frequently used for paving roads. The Roman road-building engineers were fully aware of the usefulness of slag because of the high content of iron left

¹ F. W. Willmore, *A History of Walsall*, p. 241, London, 1887, claimed that iron was worked there by the Romans, but the scanty evidence is not conclusive—About the ironworks near Tiddington see below p. 47.
from the primitive smelting process, which made slag a most suitable material for strong and durable pavements. At several places in Sussex the slag has so concreted together that the road surface is still intact and almost as hard as a modern road. There is a good example of this near Holtye, east of East Grinstead, where traces of wheel-ruts are still preserved.\textsuperscript{1} The road connected the iron-working district at and around Maresfield with London and Lewes. The metalling of the road varies in thickness, but frequently it is as much as 12 to 15 inches at the centre; at the above-mentioned part near Holtye it is 1 foot thick and 15\frac{1}{2} feet wide.\textsuperscript{2}

The network of first-class roads built by the Romans assisted the development of a certain amount of internal trade. Iron articles found at Wroxeter can hardly have been meant for local use only, and some may well have been transported to London along Watling Street. The Roman roads in the Weald, such as the London–Lewes way and the eastern road which connected the iron-smelting area north of Hastings with Watling Street at Rochester, were probably used for transporting a surplus of Wealden iron to London. The road branching from the last-mentioned road near Benenden, in Kent, towards Tenterden and Lympne may have served for the transport of iron to Lympne and from there by coating vessels to places on the east coast of Kent. Export to the Continent, however, is unlikely. The iron production of Gaul, which greatly increased in the Roman period, would have made it unnecessary to import British iron.\textsuperscript{3}

ORE AND FUEL

Mining was improved in the Roman era. Although the primitive method of grubbing the ore at the outcrops continued, there is evidence of pitting. Pits shaped like pudding basins 9 feet deep, 12 feet in diameter at ground level and 4 feet at the bottom, where a small heap of ore was found, have been discovered at Petley Wood north-east of Battle in Sussex, dated to the second and third centuries A.D. In the Weald some more of the numerous now filled-in pits may have been worked by native miners in those days. The pudding-basin shape disproves Straker’s assumption that pits were dug which were enlarged at the bottom, so that they acquired the shape of a bell. In any case it is difficult to imagine how undercut pits such as the bell pits could be dug in the Hastings beds.\textsuperscript{4}


\textsuperscript{2} E. Straker and I. D. Margery, ‘Ironworks and Communications in the Weald in Roman Times’, \textit{The Geographical Journal}, vol. xci, no. 1, July 1938. A map of the Roman roads is added on which the metalled layers are marked — Slags were also used for paving streets in Roman towns, e.g. in Rouen, in France, and at Cardiff (two streets), Davies, pp. 99 and 154.

\textsuperscript{3} Davies, p. 140 — Forbes, p. 469.

\textsuperscript{4} ‘Fieldwork during the Season 1952’ [by Colonel C. H. Lemon], \textit{Tr. of the Battle and District Historical Society}, 1952, pp. 28–29 — Straker, pp. 105–106, referring to bell pits as an
The Iron Industry in Roman Britain

Underground mining was introduced by the Romans. This is clearly demonstrated by an iron-mine cut in the dolomite-rock of the Carboniferous Limestone series in Lydney Park, south of the Forest of Dean, in Gloucestershire, in the middle or later part of the third century A.D.

The iron-mine at Lydney is the first in Britain which can be assigned with certainty to the era of Roman occupation. The construction was

as follows: a passage from 3 to 4 feet wide was cut into the rock to a depth of about 5 feet. The passage commenced at a spot at which a hut had been erected on the debris at some later date, and extended, sloping slightly downwards, for about 18 feet. It was evidently an exploratory road cut by the miners, who followed a band of ferruginous marl hoping it would lead to a body of ore. Eighteen feet distant from the entrance to the passage a shaft begins, cut into the rock. Other mining shafts found throughout the Forest of Dean also 'justify their popular ascription to the Romans'.

'Exceedingly ancient method of mining' based his assumption merely on the flint mines in the chalk of the Sussex downs.

The Iron Industry in Roman Britain

The nature of the tools used by miners in the Roman period can be inferred from incisions found in the band of ferruginous marl in the above-mentioned iron-mine in Lydney Park. The shape of the incisions suggests that they were made by short pick-hammers like those used in the Middle Ages and still later, up to the time of the introduction of gunpowder in mining. Such picks were commonly used in the Roman era; similar picks were employed in Roman iron-mines in Spain. A model iron pick, found in the floor of the late third-century hut which adjoined the Roman iron-mine in Lydney Park, is shown in the above illustration.¹

The various stages of ore-dressing were widely applied in the Roman Empire; the ore was crushed or pounded with hammers so as to reduce it to a suitable size, sorted by hand and washed. Clay-ironstones were generally washed at the pit-head to remove some of the gangue.²

Since in Roman Britain mining and smelting were extended to the compact red haematites of Lancashire, roasting became imperative, to make the ore more porous. The spathic ores mined in Sussex required pre-roasting to drive off combined water and carbon dioxide. Ore-roasting ovens were discovered at Wilderspool, in Lancashire, the use of which was indicated by a mass of haematite ore found embedded in the clay; there was a similar oven at Tiddington, in Warwickshire.³

In the principal iron-working area of Roman Sussex, north of Hastings, the ore was roasted at the pit-head, as is clearly shown at Petley Wood. The ore mined in the district was spathose iron ore, where the carbonates of iron had been converted into hydrated peroxide. At Petley Wood, at the Roman site of Footlands near Sedlescombe, at Chilcombe, and at Beaufort Park, all situated in the Sussex area, artificial mounds have been discovered showing alternate horizontal layers of charcoal, of burnt ore—which because of the large amount of metal left in it is identifiable as roasted ore—and of clay, which evidently served as a cover. At Beaufort Park vertical holes of small diameter pierced into the heap were discovered, apparently designed to secure access of air. The whole arrangement indicates a process closely resembling that of coaling the wood, or charcoal burning. The residue which remained after each roasting was not cleared away, but a new surface was prepared on top of it. A short distance away from the roasting hearth at Petley Wood a flat heap was found at which the roasted ore was stacked ready for removal to a furnace. Remains of furnaces were not discovered at either of these sites. Only at Chitcombe there were waste tips or refuse heaps indicating that a smelting furnace was in the immediate vicinity.⁴

¹ Hart, p. 25 — Arch., vol. Ixx (1904), p. 328, Fig. 12 and Plate Ixx.
² Davies, pp. 38 et seq.
³ May, loc. cit., pp. 26–27; for Tiddington see below p. 47.
⁴ VCH, Sussex, vol. ii, p. 243 (ore); vol. iii, p. 32: the layers found in the large mounds in Beaufort Park each consisted of thinner layers, made up (from below) of: (1) charcoal;
The ore was still generally smelted without addition of a flux, which meant that a large part of the iron was wasted, 50% and more remaining in the slag. Occasionally, however, lime was added as a flux. Apparently this was done early in the first century A.D. at Margidunum in Nottinghamshire, and in the second century at Woolthorpe in Lincolnshire, and as a result the slag found at Margidunum contained much less iron (about 40%). The impure siliceous ores from the Lias employed at both places required the addition of a fluxing agent to assist the fusion of the siliceous gangue by forming more fusible compounds. Use of a flux, however, was by no means universal. At Wilderspool no flux was added, but to make the silica run off and to set free the iron, two different ores (haematite and clayband iron ore) seem to have been mixed together.¹

The principal fuel employed in the Roman era was charcoal. Peat also may have been used, especially in Scotland. In most places where mineral coal crops out within the area occupied by the Romans there is evidence that it was exploited, most extensively in the civilised southwest (Somerset coal). In the military region of the north, coal from the Tyne-valley, from Cumberland and from the Scottish coalfields was regularly used in the frontier-forts. It was employed mainly for heating, but also for the smelting of lead. It has been assumed that it was used for the smelting of iron at Wilderspool, but the result does not appear to have been favourable.²

THE VARIOUS TYPES OF FURNACES

The furnaces operated in Roman Britain may be divided into two different classes. The larger of these is represented by the bowl-furnace used in Britain since the earliest stage of iron-smelting. The other class consists of furnaces not known in pre-historic Britain, but introduced by the Romans from technically advanced provinces of their vast Empire.

The bowl-furnace survived in the whole of Britain throughout the Roman era. At Castle Law, in Midlothian, in an earth-house erected

¹ For Maridunum, see Transactions of the Thoroton Society, vol. xxxi, p. 66; for Woolthorpe, where a certain amount of oolitic limestone possibly used as a flux was found among the charcoal, see Antiquaries Journal, vol. xii, p. 266 — For Wilderspool, see May, loc. cit., p. 23 — The addition of flux was not uncommon in Antiquity, Forbes, p. 36.

The Iron Industry in Roman Britain

between 115 and 140 and occupied during the second century A.D., a pit not more than one foot across had been quarried out of the rock floor. At the time of excavation it was filled with charcoal and iron slag.\(^1\) An improved bowl-furnace of the second century A.D. was discovered in Constantine's Cave, in East Fife, Scotland. It consisted of a stone basin 3 inches deep and 15 inches in diameter. The basin was encircled by two concentric stone rings with clay between them. Fragments of clay scattered around and partially coated with iron slag may be taken as indicative of a superstructure, since some of the fragments had a kind of splay foot which fitted well over the lid of the stone basin. A cleft in the roof of the cave formed a draught-hole by which the cave was freed from smoke and fumes.\(^2\)

Although the locality was outside the sphere of Roman domination, Roman influence is unmistakable. The abundance of Roman pottery found in the cave suggests that the inhabitants exchanged the iron they worked for articles of Roman make. Roman influence was strongest in Scotland in the second century, the period in which the furnace was functioning.

Several small furnaces apparently of the same type and operated from the fourth century almost until the end of Roman domination, were at Din Lligwy, on the north-east coast of the Isle of Anglesey. This settlement, enclosed by a stone wall, was probably erected as a Roman outpost to keep a watch on a landing-place in the vicinity against the approach of invaders by sea. The furnaces were circular with internal diameters varying from 1 to 1½ feet. They were on the floor level or 'a little above it'. In one of the furnaces the bottom of the basin, paved with rounded stones, could still be distinguished. A slight depression in the centre was filled with burnt clay under a layer of blackish dust with lumps of iron slag embedded.\(^3\)

The only smelting furnace in the Weald of which remnants have been preserved was at Crowhurst Park near Battle. This furnace too, which was worked from a few years before the Roman Conquest until well into the second century A.D., was a bowl-furnace approximately 1 foot or a little more in diameter.\(^4\)

A new type of furnace, which had no precedent in the Celtic era in


\(^2\) *PSAS*, vol. xlix, pp. 241–242—A circular furnace bottom (residue of smelting after the bloom of iron had been extracted) was found east of Bolwick Hall, near Marsham, Norfolk, and is now in the Castle Museum, Norwich. The dimensions (kindly supplied by the Museum) are: 1 foot 4 inches across the top, 8½ inches at the bottom, depth about 11 to 12 inches. By the shape a bowl-furnace is indicated, probably operated in the Roman era, since pottery of the second and third centuries A.D. was discovered in the vicinity.


\(^4\) Remnants in the Museum at Bexhill; see also Map I, No. 9—The circular hearth at Ridge Hill (Map I, No. 26) could not have been used for iron-smelting, since the surface was completely level 'without any cavity to receive the bloom', Straker, p. 234. It may have been used for reheating the blooms preliminary to hammering.
Britain, was discovered at the Roman military camp of Margidunum, north of Bingham, in Nottinghamshire. Outside the purely military portion of the camp an industrial area existed, in which iron-smelting was carried on in the middle of the first century A.D., as is shown by numerous small pits containing iron ore, iron slag, and much charcoal ash. A novelty was the shape of the interior: straight-sided instead of having the usual circular shape of the Celtic bowl-furnaces in Britain.¹

Another type of furnace evidently first introduced in the Roman era was the so-called ditch-furnace. One of these was found at Wilderspool. It had the shape of an oblong cavity in the form of a deep foot-print or two intersecting ovals, each of which was about 2½ feet wide. The conjoined length of the two ovals was 6 feet 4 inches. Ditch-furnaces were mainly used for roasting.²

A ditch-furnace was discovered near the hamlet of Woolsthorpe, parish of Colsterworth in Lincolnshire. By the pottery found with it the furnace is assigned to about A.D. 75-150. It was a box-like structure of clay, nearly 3½ feet long and from 22 to 24 inches wide, with a sloping bottom of burnt clay. In the middle of each side there was a round hole which may have served as a tuyere hole. Both ends of the structure were open. When the north end was opened many pieces of iron slag were found which had been only partially reduced. At the other end a dished hearth was discovered, in which a large quantity of slag, ashes, and some charcoal had accumulated. Inside the hearth a small piece of iron was found. The finds indicate that the furnace was used for iron-smelting which was done in the dished hearth while the other part of the furnace may have been used for roasting the ore. The furnace itself, however, does not appear to have been a proper iron furnace. The slightly arched top of the furnace, which was pierced by circular holes each covered with pieces of Roman pottery carefully laid in position, and, in addition, a number of clay bars with holes punched through them and, further, some short clay props found amongst the objects associated with the furnace all suggest that this was a pottery furnace. Evidently it had been used for an attempt to smelt iron by a smelter who ‘apparently had new ideas, which he was trying to carry out’.³

The oblong shape of the ditch-furnace seems to have remained a favourite design in Roman Britain, in contrast to the circular shape of the ancient Celtic bowl-furnace. The oblong shape characterised furnaces discovered near Tiddington, in Warwickshire, and at Wroxeter in Shropshire.

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Near Tiddington an industrial settlement, of which the furnace constituted a part, remained in existence until the end of the Roman era. For this reason, it may be safe to presume that the remnants of the furnace represent the state in which it was during the late third and the fourth centuries, which presumption is supported by the coins found at the settlement. The remains give a very clear idea of the layout of a late Romano-British furnace. In addition, relics of an ore-roasting oven and of the walls of the building enclosing furnace and oven are preserved.¹

The casing of the furnace was built up with limestone blocks set in reddish clay. The mouth or front aperture was protected against dis-integration by hard boulders set on each side. The walls of the casing were about 1 foot 6 inches wide. Unfortunately there is no evidence as to the height of the outer walls. Their massive construction suggests that they may have been at least 1 or 2 feet high.

The inner cavity was 6½ inches deep at the time of excavation. It was rectangular except at the front, and the bottom was slightly inclined towards the front aperture. The furnace consisted of a single slab of ¹W. J. Fieldhouse, Th. May, F. C. Welsford, A Romano-British Settlement near Tiddington, Stratford-upon-Avon, pp. 8 et seq. Birmingham, 1931.
fossiliferous limestone, two corners of which were broken off and replaced by fragments of stone. The single bottom plate represents an improvement since a greater preservation of heat was achieved and the danger of moisture penetrating from underneath was lessened. For protection against destruction by heat, bottom and walls of the inner cavity had probably been coated inside with red loam or alluvial clay, which is suggested by the masses of such materials found in the immediate vicinity.

At the side of, and only a few feet distant from, the smelting furnace a hearth was discovered in the form of an irregular circle of rough limestone blocks \(1\frac{1}{2}\) feet high and left open on one side. The surface was found deeply reddened by exposure to wood flames, but no traces of slag were discovered which shows that this was not one of those furnaces used for re-heating the blooms in between the repeated hammerings required for the extrusion of slag. The most plausible explanation is that it was an ore-roasting oven. The aperture on the side facing the smelting furnace may have been smaller originally. The surrounding blocks of stone set in clay and still extending on two sides of the oven to a total length of 2 feet, may be the remains of a platform, necessary to give access to the furnace for controlling the process of roasting. Roasting and smelting furnaces built in pairs were not uncommon in the Roman Empire, e.g. at Hüttenberg, in Austria.\(^1\)

A furnace of similar shape and dimensions but slightly larger was discovered at Wroxeter, in Shropshire, the Roman Viroconium. Judging by the coins found at the furnace and on the adjacent pavement, it was operated from about 337 to 375. The walls were built of sandstone set in clay which on the outside were backed with clay and sandstone lumps gradually sloping downwards. The bottom of the interior cavity is more inclined than in the furnace at Tiddington. One item which adds to our knowledge of furnaces in Roman Britain is a platform of clay on one side of the front aperture and adjoining the wall. It is 6 by 4 feet wide and consists of clay covered with irregular blocks of sandstone.\(^2\)

The most spectacular of all the ironworks assumed to date from the Roman era is on the south side of Muncaster Head in Eskdale, Cumberland. If it really was a Roman works it would be the first in history at which water was actually used as motive power. The evidence for dating the works consists of some Roman pottery, sherds of Samian platters and fragments of Roman brick and tile, which evidence, however, is not completely convincing, since a Roman brickworks was not very distant from the locality.\(^3\)

The artificial water conduit, the supply of which was regulated from

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1 Fieldhouse, loc. cit., p. 97, see also Fig. 7 — For Hüttenberg see Forbes, p. 127.
3 'Bloomery Sites in Eskdale and Wasdale', by Ch. A. Parker and Miss Mary C. Fair,
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the pond on the hillside, probably served for conveying the iron objects produced in the two hearths to the river Esk and farther down. Hearth I is about 10 feet, and hearth II about 8 feet square. Farther up the hill traces of another, but smaller, pond are still visible, and there is iron slag nearby. This may have been the site of a furnace for smelting the iron which was afterwards worked up in the hearths. The ore (red haematite) was mined in the hills on the other side of the river Esk.

Separate furnaces for re-heating and rendering malleable the crude bloom obtained from smelting, were found at Wilderspool. By the evidence of pottery and coins they are ascribed to the second century

Fig. 8. Re-heating furnace at Wilderspool, Lancashire: plan and section. From Th. May, Warrington's Roman Remains, p. 24.

A.D. Similar furnaces, also dating from the Roman era, were discovered at Tuklat, in Bohemia.¹

The platform (AB) was roughly semi-circular at the top. It was built up in five courses of broken tiles and bricks, set in stiff boulder clay. The platform enclosed a pit lined with clay and consisting of two parts, one of which (on the A side, was 11 inches deeper than the other and had a diameter of 9 inches at the top where it joined the other part. From the base of the deeper pit a funnel lined with broken tiles and having a width of 6 inches at the top and 2 inches at the bottom, extended 7 inches downwards and opened into the front of the furnace. One foot 8 inches below the top of the platform a semi-circular floor of clay had been laid down. In front of it lumps of unspent charcoal and a few bits of cannel coal were found. Close to the furnace there were nails, clamps, a hook, the handle of a knife, and about half of a box-


The possibility that the Romans used water-power to produce blast air has been suggested by various authors such as Forbes, p. 117, and Johanssen, p. 92. Miss Fair wrote to the author in 1952 that the site 'may be taken as certainly of Roman origin', but unfortunately it was completely obliterated during the last war.

lock of thin iron plate. In the wall of the pit, underneath the lining, a small globule of glassy slag was discovered.

The structure and the finds indicate the use of the furnace, and the process employed. The higher portion of the pit (towards B) served for reheating the crude bloom. Ash and particles of slag, which would naturally exude during re-heating, fell into the deeper portion of the pit (towards A), designed to receive them, and were extracted through the funnel at the bottom. The platform held charcoal and blooms ready to be placed in the pit. The floor in front of, and adjoining, the furnace was a working-platform on which the ironworker stood. The finished products found in the immediate vicinity were apparently forged upon the spot.

A complete novelty in Britain was the welding furnace. Special furnaces for welding iron blooms into large masses were known in Antiquity, and in the early centuries of our era they spread over the Roman Empire.¹ A furnace of this type was discovered at the Roman military station of Corstopitum, south of the Roman wall and west of the present village of Corbridge on Tyne, in Northumberland. It is dated from a period prior to A.D. 340. The furnace was circular in shape with an internal diameter of about 6 feet, and a probable height of about 5 feet from top to bottom. The walls were made of rough stones set in common clay. That it was not a smelting furnace is indicated by the absence of slag in and around the furnace.²

The illustration shows how the block was built up from small blooms, which had been produced by direct reduction in charcoal fires. First, some small lumps were welded together inside the substructure of the furnace. After the foundation piece (at the smaller end of the block) was made, two pieces facing one another were inserted, and the mass heated to welding temperature. (Tuyeres of baked clay which conveyed the blast of the bellows were found in close proximity to the furnace.) Then it was removed and welded by hammering. This process was repeated several times. It seems probable that, as it was found in the furnace, work upon the block was not complete; and this is also indicated by the pieces of iron projecting at its upper or thick end, and by its very unfinished appearance. The upper central portion was little more than a mixture of iron and slag. The analysis of the interposed slag, however, proved that it was not the refuse slag which occurs in the smelting process. Probably it was oxide, produced by the oxidation of almost pure iron, perhaps as the result of a large number of small pieces of the iron having been heated preparatory to welding.

¹ Forbes, pp. 122, 131, 430, 433, 461.
Similar blocks of iron were found in the Roman villa at Chedworth, in Gloucestershire, between Cirencester and Gloucester. This villa was inhabited from the second century until about 350 A.D., according to the coins excavated at the place. The three blocks discovered were not of uniform size or weight. From marks on one of them which seem to indicate that small pieces had been cut off for some immediate use, the conclusion has been drawn that the blocks were simply unworked material ready for the smith's use.1

1 Ch. Buckmann and R. W. Hall, Notes on the Roman Villa at Chedworth, pp. 10 et seq. Cirencester, 1872. The dimensions and weights of the three blocks were (ibid., p. 30):
No. 1: 64 in. long, 26 in. round; weight, 434 lb.
No. 2: 38 in. long, 26 in. round; weight, 336 lb.
No. 3: 59 in. long, 23 in. round; weight, 256 lb.

The weight of block No. 1 is exactly the same as that of a similar block found at the Saalburg (referred to below note p. 52) and used as a lintel beam which suggests a completely different use.
The actual purpose for which such large blocks were made can only be surmised. It has been suggested that the block at Corstopitum was intended for an anvil, but this theory is very doubtful, because the iron part of the largest anvil found in Roman Britain (at Silchester) is no more than 204 lb. in weight.\(^1\) Large iron blocks have also been discovered in other parts of the Roman Empire, e.g. at the Roman fortress of the Saalburg, near Frankfurt/Main, in Germany. The large oblong blocks, weighing up to 5 cwt., were used as lintels in a stone structure.\(^2\)

The furnace at Corstopitum also represents a new type of structure. It deviates from the ordinary type of bowl-furnace, inasmuch as the walls were elevated several feet. This type, which developed from the bowl-furnace, is generally termed a shaft furnace. The only other shaft furnace ascribed to the Roman era in Britain was at a Roman site near Ely, in Glamorgan, inhabited in the second and third centuries.\(^3\) The furnace was small, having an internal diameter of not more than 9 inches. Only two courses of masonry (red sandstone) have remained. Adjoining one side of the furnace a wide platform rising nearly 2 feet above the natural ground level was found with fragments of metal on it (unfortunately not analysed). Although a little charcoal was found, ordinary coal seems to have been largely used. The slag was from haematite ore. The most perplexing find was a little hiloque about 3 yards distant from the furnace containing manganese ore of rich quality and similar to what is used in the manufacture of ferromanganese. The amount of iron in this ore is so small (1.71% of ferric oxide) that it could not possibly be used as an iron ore for smelting. The only possibility would be that ore of this kind (containing 77.14% of manganese oxide) was added to local ores for the production of steel. This, however, is a modern process. It is possible that a small, originally Roman, furnace was used at a very much later date for experimental purposes.

**IRON-PLANT AND PRODUCTION**

The layout of an entire iron-plant in Roman Britain varied in proportion to the magnitude of production. Establishments such as the one at Wilderspool, destined to meet the demands of a large military unit stationed at Chester, were considerably larger than ironworks producing for a limited and mostly rural area, or a small military post.

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2. L. Jacobi, *Das Römerkastell Saalburg*, pp. 237–238, Homburg v.d. Höhe, 1897; the blocks are preserved in the Saalburg Museum — The heaviest piece of Roman iron ever discovered was an anchor covered with wood, found in the lake of Nemi, in Italy, weighing about 8 cwt., Illustration Johansson, p. 50, Bild 32.
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A large bloomery plant contained a furnace for smelting the ore, occasionally a second for re-heating the bloom produced, and a bench for consolidating and shaping it. In this respect, the layout had not altered very much from that of a pre-Roman British bloomery, apart from the slightly greater size of its equipment. Some of the larger Roman works, such as Wilderspool and Tiddington, included an oven for roasting the ore preliminary to smelting. At Tiddington substantial walls about 2 feet wide were found on the east and south sides of the working area. They were 18 and 11 feet long and probably of equal lengths on the two other sides. The walls suggest a building which enclosed furnace and roasting oven, and still left sufficient space for the ironworkers to perform their tasks.

Iron-plants with a limited production absorbed by the demands of a small village or a few isolated farms, were of a simpler type. They were the forerunners of the numerous village smithies and of those operated at the Manors in later ages.

Apart from the smithy near Rudh' an Dunain on the Isle of Skye, which was still functioning in the early centuries of the present era, there has so far been found only one complete plant of this type in Roman Britain. This is at Coed Newydd in the parish of Penrhos-Lligwy, on the Isle of Anglesey. The smithy covered a rhomboidal space, roughly 21½ by 12½ feet, bounded on all sides by stone walls. The floor is clayey, most of it covered with a hard layer composed of fragments of coal, and coal dust bound together with iron rust. In the east corner of the floor, which is sloped slightly from west to east, two bars were found among pieces of iron slag. To the left of this corner and a little more towards the centre, two stones 9 inches high were set in the clay floor.

The remains suffice to give a fair idea of the layout of the working area in the east corner. In the centre a small bowl-furnace, apparently one foot in diameter, served for smelting the ore. The two stones placed to the left of it formed the supports for a stone slab serving as a working bench, on which the bloom produced in the furnace was consolidated, and forged into a bar. The scales hammered off the surface and the particles of slags forced out, fell on the floor, and formed the hard layer composed of iron rust and coal dust, which was discovered at the time of excavation. The temperature required for forging was apparently generated in the same furnace in which the bloom had been produced, since no traces of a second furnace were found. Mineral coal may have been used for the forging, as fragments were among the refuse in the east corner.

The weight of the bloom depended upon the size of the furnace in which it was produced. Since the prehistoric bowl-furnace still prevailed in the Roman era without any considerable increase in dimensions,

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ten blooms were still small and light in weight.¹ The heaviest blooms known are those of which the ponderous iron block found at Corbridge was built up by welding. The exact weights of the various blooms used cannot be ascertained, but as there were at least twenty single blooms, it is estimated that the average weight would hardly have exceeded 16 lb. apiece.²

There is no doubt that production of iron increased in Roman Britain compared with the preceding era, but it is impossible to estimate or even to guess the total of annual output at any time during the period concerned. One fact, however, is certain. The production of iron in Roman Britain never developed to an extent comparable with that of the principal iron-producing regions of the Empire, such as Spain, and above all the Roman province of Noricum—which included modern Styria in the Austrian Alps—which produced ores of a quality far superior to any British ores. The exploitation of these ores, which had commenced in the Hallstatt period, was greatly intensified by the Romans, and laid the foundations for a steel industry which remained renowned throughout the Middle Ages and up to the present day.

STEEL

The prehistoric method of producing steel directly from manganese-bearing ores was continued in Roman Britain. The red ore frequently occurring at Petleywood north-east of Battle and in the neighbourhood, which belonged to the principal iron-working area of Roman Sussex, contained manganese and titanium, two excellent components for steel-making. The ore had approximately the same percentage of manganese (MnO 1.30%) as the high-quality ore (MnO 1.2%) mined in the Styrian Erzberg (ore-mountain) near Eisenerz in the Roman province of Noricum.³

In Roman Britain carburisation was still the result rather of accident than of design, which is shown by the composition of two blooms, one from the early and the other from the late Roman era. The piece of iron produced at Woolthorpe, Lincolnshire, between about A.D. 75 and 150, included slag, crystals of pure iron, and zones of a steely structure with

¹ Two Sussex blooms dating approximately from the fourth and early fifth centuries had weights of 6.66 lb. and 2.75 lb. respectively, Neur. Tr., vol. xvii, pp. 197-198.
² cf. p. 50.
³ Analysis, made by the British Cast Iron Research Association, at Bordesley, Birmingham: SiO₂, 8.5%; FeO, 17.6%; Fe₂O₃, 41.4%; TiO₂, 0.05%; Al₂O₃, 4.0%; MnO, 1.30%; CaO, 1.62%; MgO, 2.86%; H₂O (= combined water), 7.25%; CO₂ (= carbonic acid), 15.6%. A partially reduced (roasted) ore found at the same locality had a higher content of titanium (TiO₂, 0.47%), but less manganese (MnO, 0.54%).

a carbon content varying between 0.2 and 0.5%. A still greater variation of carbon content was found in the various pieces of which the block of iron found in Corstopitum on Tyne was composed. Microscopic examination proved that they contained carbon varying between 0.5 and 1.5%.

Although the Romans were well acquainted with the method of hardening steel by quenching, they did not always realise that the metal should first be carburised. This is significantly shown by a Roman chisel found at Chesterholm, Northumberland, the date of which is assigned to the second century A.D. The carbon content varied from less than 0.1% (i.e. wrought iron) to 1.3% (high carbon steel) owing to the varying conditions in the smelting furnace, which made it inevitable that parts of the metal should have a higher carbon content than others. Hammering alone was not sufficient to equalise the composition of the metal. Local heat treatment had been applied to the cutting edge of the tool so as to harden it. The edge had been heated to a temperature of about 900° C and then rapidly quenched in water, but because preliminary carburisation of the edge had been omitted it remained heterogeneous in structure, about half of it being hard and the other half soft iron. However, despite its imperfection the chisel was apparently used as a tool, since there are signs of cold working on the head.

Even if the cementation process was employed, in which wrought iron was converted into steel by heating to a high temperature in contact with carbonaceous matter, the desired result was not always achieved. This is proved by a bloom found at Nanny's Croft in Arundel Park, Sussex, close to the Roman Road. The bloom appears to have been worked some time around A.D. 400.

Microsections of the bloom, which weighs 305 grams (0.66 lb.), shows a high degree of carburisation, possibly to the extent of 1.5% of carbon, but distributed unevenly. Carburisation was achieved through considerable heating, the temperature in the furnace perhaps having reached 1100° C. Since the carburised metal was found too hard, it was subjected to the process of annealing in order to soften it. Annealing was done by letting the metal cool down slowly to a temperature below 700° C. A second heating to about 1000° C seems to have followed, because the bloom was still found to be too hard. At about 900° C the bloom was quenched in water. At the end of the process the metal was

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1 Antiquaries Journal, vol. xii, p. 267 — Grantham Public Library and Museum, Tenth Annual Report, 1931–1932, Plate iv, 4, showing junction of steely zone with the pure iron surrounding it.
2 90, vol. lxxxv (1912), p. 123, and photo-micrographs, Plate vi, Figs. 1 and 2 — See also App. I.
still too hard for forging and was evidently discarded, since it was discovered among fragments of slag.

A much better result of carburisation combined with annealing is represented by a Roman axe discovered at Silchester in Hampshire and ascribed to the fourth century A.D.

The axe, which is similar in shape to a Roman axe found in Gloucestershire, was made from siderite ore, as is shown by the arsenic content (App. I). There is no evidence of such ore anywhere near Silchester, but the blooms welded into the large block at Corstopitum, Northumberland, showed a similar content of arsenic (App. I). The layers of the axe, which were piled and welded together before the axe was forged, are of wrought iron which had been carburised. The carbon content varies from below 0.05% at the junctions of the layers to more than 0.6% in the central portions of the layers, which is typical of a steel that has been forged at a temperature falling to approximately 700° C. and then been subjected to a prolonged annealing at about 650° to 700° C.¹

The process of ‘steeling’, by which steel was welded on to an iron object, was practised in Roman Britain. The pane of a hammer found at the Roman frontier fort at Newstead in Scotland, which was occupied as early as the end of the first century A.D., shows the steel welded on to it. Another hammer from Roman Silchester shows every appearance of having had a thin plate of steel welded on in exactly the same manner as is usual in the making of hammers today.²

Another way of steeling a finished article of wrought iron was sur-

¹ Coghlan, pp. 189-190.
face carburisation. On nails found at Roman Ariconium, in Herefordshire, such local carburisation is to be seen.¹

Tempering, whereby different degrees of hardness are imparted to the metal, is supposed to have been a Roman invention. The equipment of military workshops discovered at Corstopitum and dated to the third and fourth centuries, suggests the use of tempering. Each workshop was equipped with a furnace and with water tanks some of which were cut into the walls. Anvils, on which the objects were forged and shaped, were used, as is indicated by forge-sweepings found on the original floor, although no anvil has been preserved. A notable deposit of arrowheads, spearheads, and other weapons was also found. They were in every stage of manufacture, from the short length, just nipped from the heated bar, to the finished implement. Most of them were about 3 inches long. They had four-sided points, three-quarters of an inch long, and socketed shanks. Arrows equipped with such heads must have had considerable weight and penetrative force.²

Tempering of the arrowheads and spearheads would proceed in the following way. After the iron had been carburised and heated with charcoal in the furnace to red heat (about 850° C), it was immediately immersed in a tank of cold water. This rapid cooling or quenching resulted in great hardness combined with brittleness. To reduce the brittleness, which precluded forging and grinding, and yet to retain hardness, the operation of tempering was carried out. During this process the quenched object was re-heated up to a temperature not exceeding 300° C and then cooled in air. This reduced the brittleness considerably, but the hardness only slightly. For re-heating different temperatures were applied according to the degree of hardness, or 'temper', desired, so long as the upper limit of heat was not exceeded. Tempering made the metal tough and ductile at the same time, so that the heads could be shaped by forging, the points sharpened by grinding, and the shanks welded on to the shafts.

CAST IRON

By most authorities cast iron (containing about 2·2 to 4 or 5% carbon) is considered to have been unknown in Antiquity, but the possibility is admitted that some knowledge of it reached the Roman Empire from China where it was known much earlier.³

A few pieces from Roman Britain have been discovered which analyses (App. I) prove to be of cast iron, but there is no evidence that

¹ Woolhope Tr., Hereford, 1924, p. 28, and photograph on Plate 14, Fig. 3, showing a small portion near the outside of the nail, which is steely in character.
³ Forbes, p. 407.
they were produced intentionally. They seem to be merely chance products of an accidental increase in furnace temperature. In Britain the most ancient piece of cast iron was found at a Roman, or possibly pre-Roman, smelting site at Hengistbury Head in Hampshire. It is an irregular-shaped mass weighing approximately 2 lb. Further there were two small blocks of cast iron, squarish in section, the larger of which (6½ inches long) was found at the Roman smelting site near Tiddington and the smaller (1 by 1½ by 2 inches) at Wilderspool. The block from Wilderspool was perhaps the result of an attempt to use mineral coal, of which many pieces were collected in the Roman stratum. The higher temperature generated may have produced lquation.

The unusually high percentage of sulphur contained in the product despite the fair amount of manganese which acted as a desulphuriser, indicates the use of mineral coal for smelting, but the sulphur imparted a brittleness which made the iron unsuitable for forging. The small specimen found at Wilderspool appears to have been discarded as useless, since it was discovered some distance from the furnace.

The larger block of cast iron from Tiddington weighed 1 lb. 4 ozs. There is no evidence of the use of mineral coal, which is consistent with the low percentage of sulphur. This block is the only find of cast iron in the working area; all the others were of wrought iron. This suggests that it was a fortuitous product: perhaps a furnace accretion composed of iron with un consumed particles of charcoal, which appear in the analysis as graphitic carbon.

A statuette found at Beauport Park, north of Hastings, Sussex, is undoubtedly of cast iron, as has been proved by an analysis, but it is doubtful whether it is Roman.

FORGING AND WELDING

In Britain, as in other provinces of their Empire, the Romans made extensive use of the native smith, though specialist craftsmen such as armoursers attached to military units, were sometimes foreigners. Julius Vitalis, for instance, commemorated by a stone inscription found at Bath, was a Belgian who served as armourser to the 20th legion stationed at Chester; however the great majority of the smiths who worked for

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3 The statuette is now in Hastings Museum; an analysis was made by H. H. Coghlan. Description and illustration (actual size) by Straker (pp. 335–337), who expressed doubts about the authenticity of this find. A similar statuette, also believed to be of cast iron, was in the Collection Victor Simon which was sold in Paris and lost; there were doubts of its genuineness too. A third statuette discovered later and now also at Hastings, was examined at the Victoria and Albert Museum in 1935; it was considered unlikely to be 'earlier than the eighteenth century': evidence kindly supplied by J. Manwaring Baines, B.Sc., Curator at Hastings. See also Coghlan, pp. 77–79.
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the Roman military were British. A smithy was established at every important military station, which accounts for the slag so frequently found in Roman forts in England as in other parts of the Roman Empire. 1

The ironwork manufactured by the British smith represented a tradition unbroken since the pre-Christian era. Many of his implements and his products remained essentially the same from the first century B.C. to the end of the Roman occupation. This is clearly shown, firstly by the prehistoric finds from Glastonbury; secondly by a smith’s hoard, ascribed to the end of the first century A.D., comprising his tools and materials along with some of the finished products, which was discovered at the Fort of Newstead, east of Melrose on the river Tweed, in Scotland; thirdly by the finds from Roman Silchester, in Hampshire; and lastly by a hoard excavated at Great Chesterford, in Essex, and ascribed to the transition period of the departure of the Romans and the first coming of the Saxons. 2

The great smiths’ hoards discovered at the above-mentioned sites are each divisible into two classes. The first consists of almost complete sets of smith’s tools. The sets include anvils, one of which, found at Silchester, was much like those in common use by blacksmiths of the present day. The face (14 1/2 inches long) was nearly flat and one end formed a conical beak. The total weight of 204 lb. makes it the heaviest of the iron anvils found in Roman Britain. There were also hammers of various sizes, the largest of which, found at Great Chesterford, and corresponding to our sledge-hammer, had a weight of 8 lb. A fore-hammer from Newstead weighing 4 lb. 1 1/2 ozs. would be too small as a fore-hammer for a modern smith, but it would have been very useful for making sword blades or spears. A cross-paned hammer, also from Newstead, appears to have been used for driving in nails, and a tool known as a drift, 5 1/2 inches long and oval in section, was used to make the eye-holes of hammers. Tongs of different types and chisels were also found. The second class consists of articles forming the stock-in-trade of the smith and evidently made for sale. They include bars of iron, a chain with hooks, ponderous coulters (from Great Chesterford) made for ploughs and weighing from 14 to 16 lb., anvils (from Silchester) in a form still in use by shoemakers, and small anvils for mowers (from Newstead) which have ceased to be used in England, but are still employed in Italy, Spain and South America. The mower sitting on the ground hammers out the edges of the scythe upon the

1 Forbes, p. 461.
anvil planted upright between his legs. The hoard also included planes for carpenters, shears, saws, choppers, files, padlocks, bolts, nails, and knives.

Roman cutlery varies in pattern and size. Butchers' knives ranged from 6 inches to 9 inches in total length, scissors and shears from 5 to 12 inches. The most important relics are the pocket, or shut, knives, which appear for the first time in history under the Romans. They lack the spring and the nail nick to open the blade which are found on modern knives. The Roman method of making cutlery is recorded on the tombstone of a cutler of the first century A.D., preserved in the Museum of the Vatican. Two men are depicted forging on an anvil, with a fire in the background. Above the hearth some tools, such as tongs, a knife resembling a butcher's cleaver, and a sickle, are suspended.¹

Welding was no less important in Roman times than in the prehistoric era. Since the blooms had not increased very much in size, and frequently hardly exceeded those produced in pre-Christian Britain, welding was still required to produce longer bars. Two bars found at Coed Newydd, in the parish of Penrhos-Lligwy, Anglesey, showed distinct lines at the rusted junction instead of presenting a uniformly oxidised appearance. Allowing for the crusts of rust of which one nodule weighed 1 ½ lb, when detached, the weight of the bars in the original state was about 10 to 12 lb, but hardly more.²

A method of joining which had no precedent in the prehistoric period of ironworking in Britain was to solder two pieces of iron together with the aid of copper, apparently a forerunner of the more modern practice of brazing. This method was practised in the Roman city of Uriconium (Wroxeter, Shropshire) as shown by an iron ferrule: a deep iron ring almost like a modern serviette ring. The ferrule was made from two small pieces of iron, hammered out into two rectangular strips which were welded together into one long strip. The weld was relatively good at the top end, but shows somewhat inferior workmanship at the bottom end, where the metals were not in proper contact but separated by slag and oxide. After welding, the strip had been bent over to form a circle and the two ends tapered and freed from oxide. Then they had been joined by soldering with copper which contained a little iron.³

There is no doubt that the Romans increased production and developed a large and thriving iron industry in Britain, but one must agree, on the whole, that they did not introduce 'any new technical processes'.⁴

² Examined by Professor Gowland; one bar 24 ½ inches long by 1 ½ inches square, weight 7 lb. 12 ozs., the other 20 inches long by 2 inches by ½ inch, weight 9 lb. 3 ozs. — *Arch. Cambrensis*, sixth series, vol. xx, p. 92.
The Iron Industry in Roman Britain

Just as in other provinces of their vast Empire the Romans adopted, and continued to use, the devices and methods they found in use by the native ironworkers, at the same time, however, advanced methods, which they found in regions noted for superior technical skills, were introduced by them into less developed provinces of their Empire. In this way Britain, notwithstanding her remote position, gained by being incorporated into the Empire, for improved methods hitherto not known to the pre-Roman population were introduced. A form of deep-mining was first established by the Romans in the Forest of Dean. New types of furnace, like those operated in other Roman provinces, were set up in Britain, the most advanced of which was the furnace at Corstopitum. This, though employed for welding single blooms into a large block of iron, is actually a shaft furnace, a type evolved from the bowl-furnace but distinguished from it by walls rising considerably above the ground. Improvements in respect of smelting were also achieved in the Roman period of British history, at least at some sites. Blast production by bellows in pairs which ensured a more constant supply of air, though known in the Celtic era, appear to have been adopted more generally in Roman Britain.1 The mixing of different ores to ensure a higher yield (at Wilderspool), and the addition of fluxes (at Margidunum and Woolthorpe) to promote the fusion of siliceous gangue occurred occasionally. As a result a higher yield from the ore was obtained and a smaller proportion of metal was lost in the slag. Slag with less than the average 50% of iron was found at quite small and remote sites such as Diu Lligwy, Anglesey.2 The first example of iron welded with the aid of copper, as in the more modern practice of brazing, comes from Roman Britain. A complete novelty in Britain was the practice of tempering, whereby the quality of arrowheads and spearheads was greatly improved.

The majority of the improvements achieved in the five hundred years of Roman rule fell into oblivion when the Romans left and were succeeded by the Anglo-Saxons. One craft, however, survived unimpaired by the breakdown of Roman civilisation: the craft of the smith, whose work represented a tradition unbroken since the prehistoric era and maintained throughout the Middle Ages.

1 Sussex AC, vol. lxxix, pp. 224–229 (at Chitcombe, Crowhurst and Icklesham, Sussex)—See also Plate v, and Map i, Nos. 3, 9, 17.
2 Nearly 2 bushels of iron slag were found, three specimens of which were examined by Professor Gowland, who found 31-96%, 31-58%, and 40-50% of metallic iron in the slag, Arch. Cambresisis, six series, vol. viii, p. 198.
CHAPTER IV

IRON IN THE ANGLO-SAXON ERA
ABOUT A.D. 410 TO 1066

DEMAND FOR IRON IN THE EARLY PERIOD

The last Roman legions left Britain around A.D. 410, and in the course of the fifth century Anglo-Saxon invasions and settlements took place. The fifth and sixth centuries in which civilisation fell to a much lower level than in the Roman period are known as the Dark Ages of early English history.

Despite the general decline of civilisation in England, ironworking did continue. The smith was held in as high esteem by the Anglo-Saxons as by all the other Teutonic peoples. Appreciation of the smith's work is signified in early legislation, e.g. in the Laws of Ine, king of Wessex. In Ine's laws, composed around 690 A.D., it was stipulated that a nobleman when he leaves his holding may take with him his reeve, his smith, and his children's nurse as the three persons indispensable in his future domicil.¹

The smith's products were needed for weapons, for agricultural and domestic implements no less than before the departure of the Romans. Consequently, iron weapons and implements were frequently found in Anglo-Saxon graves of the pagan period (from the fifth to the seventh centuries) in all parts of the country. There are agricultural tools such as scythes and sickles, and shears very like the sheep-shears of the present day. There are also articles for domestic use in house and kitchen, such as bowls, cauldrons, wooden buckets with iron framework, keys, chains with hooks for suspending pots over the fire, and fire steels which were struck with flints to ignite tinder. Personal items found include buckles, brooches with iron pins, and purses with iron mounts and framework. In addition, craftsmen's tools, such as chisels, blacksmiths' tongs, and weaving irons for compressing the thread on the loom have also been found. Last, but not least, weapons, such as spearheads, the

spear being by far the most common weapon of the Anglo-Saxons, shield-bosses to protect the hand holding the wooden shield, swords, and an abundance of knives, large and small, are among the relics of this period.¹

Small single-edged knives formed an essential part of personal equipment, and these have been found in the graves of men, women, and children alike. A skeleton of an Anglo-Saxon lady found in a barrow at Hurdlow, in Derbyshire, had near the right shoulder a canister containing thread, two pins or broken needles and a mass of corroded iron consisting of chainwork and keys, and at the hip a small iron knife.² The knives found in Anglo-Saxon graves vary in length from 3 inches upwards, but are mostly about 6 inches long. Larger knives are called 'scramasaxes', or sword-knives, but it is difficult to distinguish them from the knife proper, as one merges into the other as regards size; both were used as weapons and also to cut up food.³ The sword-knife or scramasax proper, which may be described as a sort of clumsy carving knife, was a universal implement in Anglo-Saxon England at the beginning of the seventh century.⁴

Iron or bronze was used for hoops to bind the drinking-vessels, which were of various sizes, from cups 4 inches high to tankards in some cases as much as 12 inches high, which have been found in all parts of the country. All belong to the fifth, sixth, and seventh centuries. It is not unlikely that among the many small vessels are some of those drinking-cups which by an order of Edwin of Northumbria were fastened to posts by the main roads in places where water was accessible, for the refreshment of wayfarers. This order is well remembered as a humanitarian act of that great king who united the English tribes and established a period of peace and prosperity in a turbulent Age.⁵

MONASTIC ACHIEVEMENTS

The smiths of pagan Saxondom seem to have been of a rather strong-willed and independent nature, as is shown in the legend of St. Egwin. When Egwin, Bishop of Worcester, came to Alcester (Warwickshire)

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² VCH, *Derbyshire*, vol. 1, pp. 269-270.
⁵ S. Pfeilstuecker, *Spaentanikes und Germanisches Kunstgut in der Frühangelsächsischen Kunst*, pp. 181-183. Berlin, 1936 — Bede (*Historia Ecclesiastica gentis Anglorum*, edit. by C. Plummer, p. 118, Oxford, 1896) referred to vessels of bronze (caucos aereos) which, however, does not exclude the use of iron for hoops; bronze, considered the more valuable material, would have been mentioned in the first instance in praise of the king’s action. The sixteenth-century English historian Ralph Holinshed (*Chronicles of England, Scotland, and Ireland*, vol. 1, p. 569, edition of 1807, London) translated from Bede: ‘iron dishes to be fastened thereto [i.e. to the posts] with chains’. Concerning King Edwin see Stenton, pp. 79-80.
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around A.D. 700, he found the town peopled with smiths, who refused to listen to his preaching and attempted to drown his voice by the sound of their hammers and anvils.\(^1\)

Compared with the pagan period, archaeological evidence is very much less abundant in the Christian period of Anglo-Saxon history. When Christianity had been firmly established, between 650 and 700, the pagan habit of furnishing graves with objects for the use of the dead ceased, but there is no reason to suppose that the fabrication of arms and ornaments by secular craftsmen came to an end at the request of the Church.\(^2\) In the Christian period the most important centres were the monastic houses. Outside the monasteries craftsmen were trained in almost all branches of work, sometimes working for or with the monks. Inside the monasteries almost all the contemporary arts and crafts were practised, as manual labour was a requirement laid down in monastic rules as a safeguard against idleness.

The Benedictine monks, many of whom rose to positions of high authority, divided their time between prayer and manual labour. Perhaps the most famous is Dunstan, who lived from 924 to 988 and became Archbishop of Canterbury in his later years. The legend that he was a competent smith is crystallised in the story of his encounter with the Devil at Glastonbury (Somerset)—though a later version transfers the setting to Mayfield (Sussex), where Dunstan’s tongs, with which he is supposed to have seized the Devil’s nose, and his anvil, are still to be seen.\(^3\)

Our knowledge of ecclesiastics skilled in the smith’s craft is not confined to legends. Real historical evidence is furnished by the Venerable Bede, ‘the father of English history’. In his history of the abbots of the monasteries of Wearmouth and Jarrow-on-Tyne, of which monasteries he was a member until his death in 735, Bede speaks of one of the abbots, Eosterwini, as a man skilled in the forging and shaping of iron with the hammer.\(^4\) During the abbacy of Huetbert, early in the eighth century, the monks were noted for bell-founding and metalwork.\(^5\)

Another monastic smith is mentioned by Ethelwulf in a Latin poem, written early in the ninth century, on the abbots of his cell, which was near York and belonged to the monastery of Lindisfarne. The monk mentioned was Cuiciuin, and he is praised by the poet for his skill in the shaping of iron with the forge-hammer.\(^6\)

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3 Straker, p. 31.
Iron in the Anglo-Saxon Era

Lindisfarne and its cells were monasteries of Celtic-Irish observance, whilst Jarrow and Wearmouth adhered to the Benedictine rule. We have thus two striking instances of monks excelling in the smith's craft in both the monastic orders to which the monasteries of Britain belonged in those early ages. Both the places of monastic ironworking mentioned were in the north of England, in the Anglican kingdom of Northumbria, which extended from the Humber to the Firth of Forth between the North Sea and the Pennines.

In this period Anglo-Saxon England attained its highest standard in learning and the arts, especially in the kingdoms of Kent and Northumbria. It was the age when England, with a suddenness unparalleled in European history, arose from a primitive civilisation to become the home of a Christian culture which influenced the whole development of letters and learning in Western Europe. At the end of the seventh century and the beginning of the eighth, England achieved a unique position culturally, a position supreme in western civilisation. This glorious period is marked by the introduction of a quasi-oriental late-antique art also influenced by Roman classicism. This evolved into a specifically English art, so that the period has been called an 'Anglo-Saxon renaissance'.

One of its main instigators was Benedict Biscop, the founder of the monasteries of Wearmouth and Jarrow-on-Tyne. From his various journeys to Rome, Benedict Biscop brought a large collection of books, ecclesiastic vestments, tapestries, and paintings to adorn his new churches. For his buildings he induced masons and glassmakers to come from France. He thus re-introduced the art of glassmaking, known to Roman Britain but then long-since lost. Owing to his unceasing zeal Jarrow and Wearmouth became a focus of learning and art in Northumbria until late in the ninth century, when Danish invaders ravaged Northumbria and destroyed its culture.

The high standards of this phase extended to crafts and industries. We have seen that a leading ecclesiastic such as Eosterwini (Benedict Biscop's cousin, and his successor as an abbot) was devoted to the smith's craft and excelled in it. The impetus affected far more detailed work, such as cutlery. In the middle of the eighth century, English—and especially northern English—cutlery attained such a standard of refinement and perfection that specimens of its produce were sent as special gifts abroad. Evidence of this is given in a letter of the year 764, directed to the Englishman, Lullus, Bishop of Mainz and successor of Boniface, the great Englishman who established the German Church under the supremacy of Rome. In this letter Guthberht, abbot of Wearmouth and Jarrow, refers to presents which he had sent in the year 758 by one of his monks who set out on a pilgrimage to Rome, but died on

1 Stenton, p. 177.
the way. The sender was anxious to know whether his presents, which consisted of a cloak of otter fur and twenty small knives (cultelli), had been delivered. To these previous gifts he adds two palliums, i.e., ecclesiastic vestments of the finest work (subtilissimi operis), books, and a bell. With an earlier letter, undated but of circa 734–746, the priest Ingalice had sent a gift of four small knives. These are described as being made in a manner customary in the country (cultellos nostra consuetudine factos).

The special gifts sent abroad were objects in the manufacture of which the country—and especially the north—had excelled since the days of Benedict Biscop, such as embroidered vestments and illuminated books, and amongst these gifts are knives. This is a significant fact, more so as the knives were sent to the Rhineland, where, some centuries before, sword and knife making had attained a high standard. From the partly Romanised districts of the lower and middle Rhine there probably came the famous Nydham swords of the fourth century, and under the Frankish empire the manufacture of sword blades was a staple industry in these districts. The quality of the cutlery manufactured in the Rhineland in the fourth century was also of a high standard, as is witnessed by a knife found at Mainz. This knife was ornamented with three stars of yellow bronze surrounded by circles of copper inlaid on the top of the blade. A closely similar knife was found at Winchester, but the inlaid ornamentation is less perfect, and it may be an inferior imitation. Whilst in the fourth century knives manufactured by Romanised Germans appear to have been superior, in the eighth century the tide had evidently turned completely. There would have been no point in sending specimens from Northumbria as particular gifts to an honoured friend abroad if knives just as good, if not better, were manufactured in his own country.

The knives sent to Mainz are described as being fashioned in a special manner peculiar to the country. According to Baldwin Brown the Anglo-Saxon knife is very constant in its form, a special characteristic being its straightness, by which it differs from the curved knife of the Bronze Age and of Romano-British times. Such a distinction is, however, too general to mark it as a special characteristic of Anglian or Northumbrian cutlery. It is more likely that the distinctive characteristic of the knives sent to Mainz was the ornamentation with inlay, a technique developed in ancient Egypt and perfected in Alexandria, whence it was also introduced into the West. This technique, when

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2 Ibid., Epistola 77, pp. 215–216.
applied to metals, is commonly called 'damascening', but it differs from damascening proper, in which strands of metals of different textures and qualities are welded and forged together so that in the end a watery or streaky appearance is obtained.\(^1\) In the finds of the early Middle Ages the technique of damascening proper is confined to the blades of swords, and there is no evidence whatsoever of its application to knives, but the other technique of inlaying was applied to sword-knives and knives proper. The knives were incrusted with wire of gold, silver, or copper, and we have a very early example of this in the Winchester knife already referred to.

Of sword-knives or scramasaxes most beautiful specimens have been preserved from the Anglo-Saxon period, and amongst the treasures of the British Museum is a sword-knife of about A.D. 800 which is inlaid with Runic lettering and decoration in brass and silver wire; this knife was found in the Thames.\(^2\) There is also a ninth-century sword-knife, elaborately ornamented with inlay, which was found at Hurbuck farm, near Lanchester (County Durham), and thus very near to Jarrow and Wearmouth; this knife is part of the biggest hoard of iron weapons and implements ever discovered in this country. Both these knives are ascribed by Wheeler to the 'Hurbuck type' of the eighth, ninth, and tenth centuries, which type has normally deeply scored lines and is often inlaid with copper, brass, or white metal, the back being straight but slightly sloping-off towards the point.\(^3\) As the sword-knife and the knife proper are hardly to be distinguished from one another except by size, we may presume that the knives sent to Mainz between 732 and 758 were of the Hurbuck type.

As to the design used for inlaid ornamentation, it has been suggested that the Syrian vine-scroll, which is a motif characteristic of Northumbrian art, was applied. Such inlaid scroll patterns are seen on the blade of a highly ornamented knife found at Sittingbourne in Kent and assigned to the ninth century; in this knife, which is illustrated in Fig. 11, the maker's name, 'Biorhtelmme', is also inlaid, with silver letters. The inscription closely corresponds with the Runic inscription on a Northumbrian silver brooch found near Chatham in Kent and now in the British Museum, and also with inscriptions on a sun-dial on the wall of Kirkdale Church, near Kirby Moorside (Yorkshire), and on the shaft of a cross found at Alnmouth, Northumberland.\(^4\) Thus it may be inferred that the Sittingbourne knife was of Northumbrian manufacture.

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\(^1\) Originally an Indian process which may be traced back many centuries before the Christian era, and described by N. Belaiew, Jo., 1918, No. 1, p. 433.

\(^2\) BM Guide, p. 96. The author is much indebted to Mr. R. Bruce-Mitford, Keeper of the Department of British and Medieval Antiquities, for showing him the knives in the British Museum, despite the tremendous work caused by reorganisation after the war-time evacuation.


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These three specimens give an idea of the shape and ornamentation characteristic of the knives sent to Mainz which justified the sender in using the phrase 'nostra consuetudine factos'.

The influence of English culture can be traced wherever the Anglo-Saxon missionaries went in the eighth century, for example in West, Central, and South Germany. To these parts of the Continent English knives were sent. Some specimens have been discovered in a sand pit near Strasskirchen, south-east of Straubing in Bavaria, in Oberfranken (northern Bavaria), and at the village of Goddelsheim, in the former principality of Waldeck in Central Germany.¹ These knives, excavated in burial places of the late eighth century, all have the angular shape characteristic of the contemporary English knife of Northumbrian origin.

THE SMITH AND HIS WORK

Some essential products manufactured by the Anglo-Saxon smith in about A.D. 1000, are referred to in one of the books written by Ælfric, who became abbot of Eynsham monastery in Oxfordshire in about A.D. 1005. A celebrity in the world of learning, he was also a great patriot, inciting his countrymen to a vigorous defence against the invading bands of Danes, and exhorting them in his sermons by citing examples of fortitude and self-sacrifice from English history.

The book which did most to establish his reputation, and bring him general fame, is his Colloquy, an imaginary dialogue in Latin and English, designed to teach his scholars correct Latin. In this Colloquy,

¹ Germania, vol. 20 (Berlin 1936), illustration: Tafel 42, Abbildung 1, No. 3, facing p. 290; vol. 22 (Berlin 1938), illustration: Tafel 11, No. 4, facing p. 45. The author is indebted to Professor Haefl of Würzburg University, Bavaria, for drawing his attention to these German discoveries.

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various craftsmen are extolling their services to the community. One of them is a blacksmith who says, 'How does the ploughman get his plough or his ploughshare, or his goad, but by my craft? How does the fisherman obtain his hook, or the shoemaker his awl, or the tailor his needle, but by my work?'

The smith's work at this period is illustrated by a picture (Pl. VII) taken from an early eleventh-century manuscript, which contains an abridged translation of the first seven books of the Old Testament by the same Ælfric of Eynsham. On the right of the picture, Tubalcain is seen working at an anvil and forging a piece of iron with a hammer. To the left of the anvil stands a man holding tongs in his right hand, ready to lift the iron when finished but still hot. In his left hand he holds a toolbag.

The skill of the smith is revealed in the forging of shield bosses (see Pl. VIII). The shield, which was all that the early Anglo-Saxons had for the protection of their bodies, was an orb of wood generally circular and probably covered with a hide. For the grip, a round hole was cut in the centre and crossed by a bar which was grasped by the left hand. For the protection of the hand, the aperture in the shield was covered outside with a hollow boss of iron which projected some 3½ to 6 inches. The boss was attached to the woodwork by means of rivets run through holes in a horizontal rim like the brim of a hat at its base. Similar rivets fastened the holding bar which was sometimes extended on each side, so as to give a firm grip of the wood.

The technique of the weapon smith was as follows. Since he had no plates at his disposal, he had to hammer everything out from the lump of iron. This however was an advantage, since it made the iron much more compact and tough. Apart from an exceptional example (shown on the right in Pl. VIII) the shield bosses are all in one piece. The piece of metal was beaten from the centre. The blows of the hammer drove the metal outwards and thickened it, while it was thinned where the actual strokes fell, with the result that the metal at the top was thinner and gradually got thicker, so that below the thickness was 3 times that of the top. When the smith had produced a flat lump of iron approximately circular in shape he beat it over the rounded head of a slender stake until the central part was forced up into a knob. Heating this up repeatedly he struck into the knob from the side with the rounded edge of a suitable hammer until it was worked into a narrow stem with a lump at the top which formed the terminal stud or button. After this, the smith transferred the piece to a broader round block and began to beat the iron out from the centre towards the circumference into the desired shape, making a horizontal rim. The outer circumference of the rim was then trimmed with a chisel. The result of the forging was a hollow dome carrying a solid stem crowned by the button or stud. All

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this was done by hammering alone without welding or any other joining.

The shield boss (shown on the right in Pl. VIII), now preserved at the Ashmolean Museum at Oxford, is exceptional. It has a conical form and is constructed in a different fashion. The piece was put together with a framework and filling in the same way that the Saxon helmets, which were generally conical in shape, were constructed. The shield boss has six ribs and the plates are carefully fitted in between these with strengthening pieces skilfully fashioned. A shield boss of this shape was found at an Anglo-Saxon burial place assigned to the seventh century A.D. at Farthingdown near Coulsdon, in Surrey.¹

The high esteem the ironworker enjoyed in Wales is signified by the prominent position accorded the smith in the Laws of Hywel Dda, a codification of old Welsh laws made shortly before A.D. 950 and associated with the name of Hywel the Good who was king of South Wales and, by tradition, also overlord of the whole of Wales. The king's smith, who made the weapons of war, was one of the important officials of the Royal court. The smith belonged to the free tribesmen who constituted the superior class in Welsh society. If the son of a taeg, i.e. a member of the second class which was bound to the soil, wanted to become a smith, he needed his lord's consent. Each 'tref', i.e. hamlet, seems to have had a common smithy, which had to be situated some distance away from the other dwellings because of the danger of fire.²

Of particular interest among the iron objects from Ireland manufactured in the same era, are bells made of wrought iron, used by ecclesiastics and monks of the early Irish church to summon their congregations to prayer. Many of these bells came to be cherished as sacred relics in the course of time, and were encased in shrines of more expensive material such as bronze. The bell of St. Patrick, who converted pagan Ireland to Christianity during the years 432 to 461, is a fine iron bell riveted and brazed together.³ The iron bell of St. Cuilean (Pl. IX), brother of Cormac who was the king-bishop of Cashel and died in 908, was discovered in a hollow tree in county Tipperary; in the eighteenth century it served as a sacred object on which oaths were taken.⁴ It was coated with bronze, and encased in a shrine of the eleventh century. The bells of the age were quadrangular in shape having four sides or faces, which was necessitated by the method of construction. The wrought iron plate from which the bell was forged was hammered into

³ Gardner, I, p. 52.
⁴ BM Guide, loc. cit., pp. 141–142. There are also fragments of three other iron bells connected with Irish saints of the seventh century, in BM, and the bell of St. Conall, which is 7 inches high and consists of an iron plate hammered and riveted down the side.
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shape and riveted down the side. The custom of using such bells spread from Ireland to the Continent as far as Switzerland, probably owing to the missionary activity of Irishmen. It also extended into England and Wales, as is shown by the sending of a bell from Northumbria to Germany as mentioned above, and by a quadrangular bell made of two iron plates riveted together, which was found at Pennydarren Farm in Breconshire at the alleged site of a saint’s chapel.¹

EXTENT AND REGIONAL DISTRIBUTION
OF THE INDUSTRY

Evidence of iron smelting is scarce but not entirely lacking. It dates mainly from the very early and from the final period. Despite the incompleteness of the sources, it is not impossible to decipher in outline the approximate extent of the iron industry.

By a charter of 689 Oswe, king of Kent, granted to Adrian, abbot of St. Peter at Canterbury, land which belonged to the manor of Liminge, i.e. Lympne in Kent, on which there was an iron mine.² This seems perplexing, as Lympne is very distant from the iron district of the Weald, but in the early Anglo-Saxon era stretches of woodland used as pasture for swine were frequently attached to distant manors. To Liminge or Lympne a stretch of woodland in the Weald of Kent was apparently attached, which is indicated by the ancient name of ‘Limnenwara wald’ recorded in the eighth century.³ For this reason the iron mine was probably on the fringe of the Weald of Kent some distance west of Lympne. Possibly the ore obtained was smelted in one of the ancient bloomeries around Brede, in south-east Sussex, which constituted an important centre of ironworking in the Roman period.

In the Midlands and the North also iron may have been mined and smelted in the early period.

In Warwickshire smelting seems to have continued for approximately 150 years after the departure of the Romans, since the Romano-British settlement near Tiddington, at which a bloomery was operated in the Roman period, is supposed to have survived until about A.D. 556.⁴

It may be inferred from finds that iron ore was mined in the north of England. A hoard of swords, scythes, tools and buckles or brooches (without pins) and axe-heads, all of iron, found on the farm of Hurbuck

¹ Now in the National Museum at Cardiff.
⁴ W. J. Fieldhouse, loc. cit., p. 4 — Evidence from a burial place near Alstonfield (on the border of North Staffordshire and Derbyshire), associated with two coins of the fourth and eighth centuries, is too uncertain for any definite conclusion. Among the finds there were ‘lumps of iron that had been subjected to great heat’, which, however, may have occurred during cremation, VCH, Staffordshire, vol. 1, pp. 202 and 289.

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near Lanchester, in County Durham, also contained an iron object resembling a miner's pickaxe of the present day. It is 10½ inches long, pointed at both ends, and perforated in the centre to accommodate a shaft. The pickaxe suggests that iron ore was mined in Weardale about A.D. 900. The ore would be the haematite of the district.

More evidence is available from the final period of the Anglo-Saxon era. The fair amount of iron which the city of Gloucester in every year was due to supply for the king's use in the reign of Edward the Confessor (1043–1066), makes it probable that the iron manufactured by the smiths of Gloucester was obtained from local ores in the Forest of Dean, which was the nearest centre of ore-supply, and smelted in the Forest. The amount of iron which the city had to deliver was 36 'dices' (each being a lot of ten) probably in the form of horseshoes, and, in addition, one hundred iron rods suitable to be elongated for the making of nails for the king's ships. At Hereford there were six smiths in the time of King Edward. They used to pay one penny each for their forges, and each of them made 120 horseshoes yearly from the king's iron. This iron was probably obtained from the ancient mining and smelting district near Ross on the Wye; at Merchelai north-east of Ross one lump of iron (massa ferri) was paid as a customary rent.

More definite evidence of ironworking is available for the south of Somersetshire where Edward the Confessor held the manor of South Petherton. The customary rent paid to this manor from Cruche, i.e. Cricket St. Thomas, was, amongst other things, one bloom (bloma) of iron from each free man. Similar rents were paid by Bickenhall and Seaborough, also in the south of the county.

In the area of Rockingham Forest, in the north of Northamptonshire, iron was worked extensively. The forest, a favourite hunting ground of the Saxon kings, ensured ample supplies of wood for charcoal-burning; at Corby as well as at Gretton ironworks were operated in the time of Edward the Confessor. In the south of the county smiths worked at Greens Norton and Towcester. Judging by the considerable amount of money they paid, there seemed to have been no small activity. All these ironworks in Northamptonshire were on the desmesne land of the Saxon kings. Ironworking, however, came to an abrupt end at the close of the Saxon era. At the time of the Domesday Book of 1086 the rents were no longer paid by the smiths, and ironworking in Rockingham Forest seemed to have been on the wane, if it had not ceased altogether.

2 See Map II.
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Probably the Saxon iron industry in Northamptonshire came to a sudden end in the rebellion of 1065 in which Earl Morcar led the men of North England to Northampton where 'they slew men and burned houses and corn', so that the whole shire and other adjacent shires were 'for many years the worse'.

Ironworking continued in Scotland, but evidence is scarce. At Fersit near the River Teig, in the south of Inverness-shire, smelting, probably of bog iron ore, took place, as witnessed by slags. Swords found suggest the eighth century as a possible date. At Bonnybridge on the north side of the Antonine ditch smelting operations were carried on in the post-Roman period and well into the Early Middle Ages.

The regional distribution of mining and iron working at the end of the Anglo-Saxon era appears to have been approximately the same as in the final period of the Roman occupation. The Forest of Dean with the adjoining areas of Herefordshire and Somerset apparently retained the position of the principal iron-working region which it had acquired by the fourth century. The most remarkable change was the shrinking to the verge of extinction, of the Wealden iron industry. Under the Romans it had rivalled the industry of the Forest of Dean, and in the early phase of the Roman regime it had even been superior. At the end of the Anglo-Saxon era one ironworks (ferraria) is on record for the Weald, near East Grinstead in Sussex, and there was possibly another at Stratfield Turgis in the north of neighbouring Hampshire.

FURNACES AND QUALITY OF IRON

No remains of furnaces have been discovered from the Anglo-Saxon era. Since the bowl-shaped furnace prevailed throughout the Roman period and was still used in Medieval England, it may safely be assumed that it also represented the type of furnace in which iron was smelted in Britain during the intermediate period. This view is corroborated by finds made in the south of Ireland. At Ballyvourney, County Cork, a number of pits were excavated, several of which contained iron slag and what has been described as 'furnace bottoms'. At this site, which was inhabited during the sixth and seventh centuries A.D., a total of 57 complete furnace bottoms were found, and fragments of eighty others. They are lumps of porous, slag-like material, mostly circular in shape, flat or concave on one side and convex on the other. Such lumps were discovered on the Continent also, and are explained as a residue of smelting, which after the bloom had been extracted collected in its

1 Darby, p. 167 (from the Anglo-Saxon Chronicle) — VCH, Northamptonshire, vol. 1, pp. 304-305.

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place, where they cooled and coagulated into the shape of the dish-shaped bottom of the furnace. Since the lumps varied in diameter from 3 1/2 to 7 inches, the internal diameter of the circular base of the furnaces (but only the base) seems to have been 5 or 6 inches. Nothing remains to show the depth or the diameter at the top of the pit. Fragments of clay cakes from 1 1/2 to 2 1/2 inches thick, flat or convex on the upper surface and concave on the under side which is burnt red from the heat, are indicative of a clay lining and in some cases possibly of a small superstructure, which may have had a central hole on the top for the escape of smoke. A slightly curved piece of clay found some distance away may be a fragment broken from the clay nozzle of a tuyere. The fuel used was charcoal, of which a quantity was in the pits and all over the site. The charcoal had been made mainly from small pieces of ash and hazel.¹

Furnace bottoms of similar dimensions (130 mm., i.e., a fraction more than 5 inches) were found at Ballycatteen Fort, County Cork, occupied around 600 A.D. by a community of craftsmen who had trade relations with Gaul and Britain. Additional evidence is supplied by finds made at Boho, County Fermanagh, Ulster, presumed to date from the first millennium A.D. There were two pits showing traces of iron smelting probably from bog ores. Some pieces of slag and fragments of small iron objects such as knives, horseshoes, and nails, one of which fits a horseshoe, were also found at the site. The pits had a depth of some 18 inches.²

Although the evidence is scanty and many of the conclusions arrived at are conjectural, it appears that from the sixth to the ninth century and perhaps somewhat later a bowl-shaped furnace was used, the dimensions of which must have been larger than those indicated by the so-called furnace bottoms, which are really only the extension of the very lowest part of the furnace. A depth of 1 foot 6 inches suggests a furnace slightly larger than the bowl-furnaces of Roman Britain, probably having an internal diameter equal to the depth. This type of furnace seems to have had a low superstructure of clay.

It is not possible to arrive at any conclusion about the size and weight of the bloom produced in the Anglo-Saxon era, but it does not appear

¹ M. J. O'Kelly, 'St. Gobnet's House, Ballyvourney, Co. Cork', Journal of the Cork Historical and Archaeological Society, vol. LVII, pp. 18 et seq., illustration of furnace bottoms on p. 33, Fig. 3. Cork, 1952 — Similar 'furnace bottoms' have been found in other Irish counties such as Clare (at Cahercommaun, eighth to tenth centuries, a total of 35), Mayo, and Meath, ibid., p. 34.

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to have been larger than in the Roman period. For small objects such as nails and horseshoes the small blooms sufficed. Weightier and larger objects such as axe heads were still produced from layers piled and welded together, before the object was forged into the shape required. This is clearly shown in the structure of a Saxon axe probably dating from the sixth to seventh century A.D., and a Danish battle-axe of 895 or 896 A.D. (Fig. 12).1

The nature of the iron had not altered either. It was still a mixture of wrought iron with steely portions and with considerable inclusions of slag. A Viking hoard of the eighth century discovered at Crayke in the North Riding of Yorkshire contained six pieces of bloomery iron. They had evidently been consolidated by the hammer, which forced out the slag, and forged into bars, but a fair amount of slag is still present which is disposed in long streaks in the direction of the hammering. The metal consists of layers of wrought iron alternating with layers of steel, the carbon contents of which are 0.4% at the maximum.2

There is, however, evidence showing that some distinction in respect of the quality of the iron was made. The hundred iron rods or bars which the city of Gloucester was obliged to render to the Crown even before the Norman Conquest were required to be ductile, so that they could be elongated by hammering, and afterwards worked into nails for the king's ships.3 The requirement that the iron should be of a special quality is an indication that the wrought or bar iron obtained from the brown haematites of the Forest of Dean was as highly appreciated in those early days as it was to be in later centuries. It was always renowned for its combination of tensility and ductility, or, as an English ironmaster of the eighteenth century worded it, it was a tough iron 'which will endure bending backwards and forwards a great many times without cracking or breaking'.4

STEEL-MAKING

The technique of making steel had not fallen into oblivion. In Anglo-Saxon literature many references are made to steel and also to 'steeling'.5 Conversion of soft wrought iron into steel by cementation continued to be practised. The technique seems to have been improved by the Danes

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1 Coghlan, pp. 149–150, 190–192.
4 'Remarks on the Nature and Quality of Iron', by Britannicus (i.e., John Cockshutt of Wortley ironworks, in Yorkshire), The London Magazine, vol. xxx, February 1752 — See also H. Powle's 'Report on Iron-making in the Forest of Dean' (Ph. Tr., vol. xxi, p. 934. London, 1678), referring to the toughness of the bar iron produced by the ironworkers 'which they esteem its perfection'.
and the Northmen or Vikings who began to invade England and Ireland in the eighth century, and who after a time settled down as farmers and husbandmen and gradually merged with the Anglo-Saxon population.

That the method of producing steel from wrought iron by carburisation and quenching was completely understood is proved by a chisel from the above-mentioned hoard of Viking relics discovered at Crayke. The iron had first been heated in a charcoal fire to about 1000° C and carburised to a fairly high degree, though not uniformly. Near the head of the metal was almost entirely steel containing 0.9% of carbon. At the side-faces patches of different composition were found, one of which contained approximately 0.4%, the other 1.2% of carbon. After carburisation the tool, but only its cutting edge, had been hardened by quenching from a temperature of 750° C or somewhat higher. The technique shows distinct progress compared with that of Roman Britain, in which it is evident that the process was not always completely understood, since carburisation was frequently omitted. The Viking smith, however, seems to have mastered the whole process.¹

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The method of partial carburisation was also understood, as is exemplified by a Danish battle-axe of 895 or 896 A.D. found in the bed of the river Lea near Stratford in Essex (fig. 12). The body of the blade has a carbon content of 0.049% which is typical of wrought iron. The structure is layered, and in places much contorted, which indicates that the iron had been piled and repeatedly forged from faggots of sponge iron. A small quantity of entrapped slag is present, which had not been expelled during piling and forging. The 'fibre' or 'grain flow' of the blade is parallel to the cutting edge. The cutting edge of the blade, but only the immediate edge, had been locally carburised by heating in contact with carbonaceous matter. The edge was then hardened by quenching in water.¹

MINING AND FUEL

Mining appears to have made no technical progress since the Romans left. Judging by the locality of the ironworks, no new ore-fields were exploited either. Ore was usually mined by pits sunk at short distances apart.

Charcoal was the fuel exclusively used in England for smelting and forging, with the exception of the northern part of the country and Scotland, in which regions peat from the vast moors supplied cheap fuel. There is no evidence of mineral coal being employed, as was first done in the Roman period. Wood for charcoal-burning was still abundant, although forest-clearing for land-cultivation and colonisation was much more extensive than in any of the preceding periods. The south of England was particularly well wooded. In the ninth century a thick belt of wood known as the Weald in Kent and Sussex, extended into Hampshire where it afterwards became known as the New Forest, and from there farther west to the border of Wiltshire and Somerset. The Midlands also were covered with large forests. Despite the steady extension of farmland the country was still well wooded in the eleventh century in which the encroachment upon the forests was counteracted by the setting apart of large tracts of forest ground as preserves for the King's own hunting.²

CHARACTER OF THE INDUSTRY

Despite the rather incomplete evidence, it may be said that the character of the iron industry was predominantly that of a home industry, as it had been in the preceding periods of British history. Iron was produced

¹ Coghlan, pp. 191-192 — Analysis, App. I.
² R. G. Collingwood and J. N. L. Myres, Roman Britain and the English Settlements, pp. 409-410 — Stenton, pp. 64-65, 279, 281, 674-675 — See also Map II.

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locally to satisfy the demands of small economic units such as the household of a nobleman, whose position was comparable to that of a chieftain among the ancient Celts, and also those of the farmers, whose numbers increased with the increasing cultivation of the land. There was little delivery of iron into the towns because the Anglo-Saxon economy was predominantly agricultural, and the organised supply of iron for the garrisons which had absorbed a fair amount of production in the Roman period, had ceased with the departure of the Roman legions. To some degree, however, it was replaced by the organised economy of the monasteries, the estates of which were often in very various parts of the country. This meant that iron products from iron-working districts were brought to those poor in the metal, so that an internal trade in iron developed. Special articles such as knives were exported, but as occasional gifts; not commercially. Others such as Irish church bells were occasionally imported into England and Wales. Such export and import, however, was on a very small scale and there is no indication of any exchange of iron products with other countries in a commercial way.

In spite of the frequent internal wars and Viking invasions which earned the Anglo-Saxon era the name of the Dark Ages in English history, definite economic progress took place in the same period. The extensive clearing of new land which characterises the era produced a marked expansion of agriculture and with it went an equally marked growth of population. Even the most cautious estimates disclose a 50% increase of population in the five and a half centuries between the end of the Roman occupation and the coming of the Normans. Both these factors necessitated an increased production of iron. It is, however, impossible to arrive at even a rough estimate of its extent. One fact, however, emerges clearly: the conquering Normans were greatly impressed by the industrial efficiency they found in England. Their appreciation is expressed in the tribute which William of Poitiers, the chaplain of William the Conqueror, paid to the skill of English artificers. He added that German skilled workers were accustomed to reside in England because of the high level the Anglo-Saxons had attained in all forms of craftsmanship.¹ In France also the skill of English craftsmen was appreciated, and knives made in England were of high repute in France during the Middle Ages.²

² C. Page, La coutellerie depuis l'origine jusqu'à nos jours, vol. 1, p. 158. Chatellerault, 1898.
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<td>Alford</td>
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CHAPTER V
DESTRUCTION OF THE INDUSTRY IN THE NORMAN PERIOD, AND ITS RECOVERY (1066-1154)

DESTRUCTION BY WAR

The sources supplying evidence of iron-working are still rare in the Norman period of English history though not quite as rare as in the preceding era. The principal source of information for the early phase after the Conquest is the Domesday Book of 1086. This survey of all England 'is unique amongst the records of the medieval world' as a record of national economy. It was compiled at the special request of William the Conqueror who desired to know more about England, its population, the state of his own estates and of those granted to his followers, and, above all, about the changes which had taken place since the end of the Anglo-Saxon regime.¹

In respect of the mining and working of iron the survey must not be regarded as an absolutely complete statistique in the modern sense. The data, however, are sufficient to give a general idea of the state and distribution of the industry.² It also reveals why in certain regions iron-working was considerably less extensive than in others. This is implied in the description of the general state of cultivation observed by the surveyors in the various counties of England after the first twenty years of Norman rule.

The most striking fact disclosed in this respect is the tremendous amount of waste land.³ A part of it, such as marshland and the rest of primeval forests, was natural wilderness. Another part had been laid waste in wars preceding the Norman Conquest. By an internal war in 1065 Northamptonshire had been devastated to such an extent that

¹ Stenton, pp. 648-649.
² Map II.
³ Darby, pp. 166 et seq.
many years later the total of waste land still amounted to about one-third of the county. The devastation no doubt affected the iron industry, which had been quite extensive in the latter period of the Anglo-Saxon regime, especially in the forest of Rockingham: in 1066 hardly any traces of it were left. Domesday Book recorded that in respect of woods and ironworks ‘very many things are wanting’, and that the rents of the smiths were no longer paid.¹

However, the bulk of the land laid waste in England had been devastated in the wars which followed the Conquest and lasted until the final subjugation of the country under the rule of William and his Normans. The south-east of the country had to bear the first impact of the Norman invasion, but not the heaviest, and apparently it soon recovered. The manor of Ditchling, near East Grinstead, Sussex, in which the only ironworks recorded in the Weald was situated, had even increased in value by 1086.² The same applies to the south-west of England, the area extending from Somerset across the Forest of Dean into Herefordshire, one of the main centres of iron-working at the end of the Anglo-Saxon period. After the ravages of the occupation and some destruction done to Herefordshire by Welsh tribes, the industry regained its importance and retained it until well into the fourteenth century. The only region in which destruction appears to have been permanent was the south of Somerset. On the demesne land of Edward the Confessor iron-working had ceased completely by 1086. It was recorded in the survey that the customary rents paid in iron up to 1066 were not rendered any longer.

It was different in the Midlands and in the northern counties, because of the consequences of the ‘rising of the North’ against the Normans in the years 1069 and 1070. The rebellion was suppressed with the utmost ferocity; vast areas were devastated deliberately, and the populations massacred. The tale of the ‘harrying of the North’ is well known in history. Domesday Book bears witness that large regions in the north were still derelict seventeen years later. It is therefore not surprising that hardly any iron-working activity here is on record in the survey. Cheshire, Derbyshire, Shropshire and Staffordshire suffered equally from deliberate destruction in those years.³

The story of devastation and plundering did not end with the suppression of the rebellions of 1069 and 1070. In the year 1104, for example, the Anglo-Saxon Chronicle records that wherever King Henry I went ‘there was complete ravaging of his wretched people caused by his court, and in the course of it often burnings and killings’.⁴ During the anarchy which marked the reign of Stephen, the last Norman king

³ Darby, pp. 169–170 — Stenton, p. 597.
Destruction of the Industry in the Norman Period

in England (1135-1154), many castles were built. The garrisons of these strongholds lived on the surrounding land by forays which they extended over constantly widening areas until the castle stood in a large territory of devastated land. The Anglo-Saxon Chronicle reported: 'you could easily go a whole day's journey and never find anyone occupying a village, nor tilled land', and it was 'always going from bad to worse' during the nineteen years of Stephen's reign. The final result of the devastations in the last period of the regime of the Norman kings, was that in 1156 vast areas all over the country still bore the marks of previous ravages. The proportion of waste land to the cultivated area was greatest in the Midland counties.

It has been doubted whether the mining and working of iron in the northern counties really came to a complete standstill. The need for iron, in particular for agriculture, required at least some small-scale production, even in thinly-populated areas, such as the north after the devastations in 1069 and subsequent years. On the other hand, whereas Domesday Book records no iron-working activity in Derbyshire, it mentions a large number of lead mines in that region. This shows that the surveyors did take account of mines, so that their failure to mention iron-mining suggests that there really was none to record: though it is of course possible that the working of iron on a small scale may have escaped their attention.

RECOVERY AND EXPANSION

The continual wars which ravaged the country, and by reducing the size of the cultivated areas simultaneously reduced the demand for iron in agriculture, produced a new demand, namely iron for military purposes. War needs iron for weapons, and for the building of strongholds and fortifications. Thus the need for iron for military purposes automatically led to measures which had the effect of repairing some of the destruction that war itself had caused.

It appears that one of the first instances of revival of the iron industry was the establishment of a new iron-working area in Lincolnshire, to replace the ironworks in the Forest of Rockingham preserved as a royal forest for the king's game. The works formerly operated in the forest and in other parts of Nottinghamshire had fallen victim to previous wars. The working of iron near Bitham in the south-west of Lincolnshire and at Stow in Well, west of Lincoln, is mentioned for the first time in

1 English Historical Documents, loc. cit., p. 200.
2 The proportion of waste to the total land was nearly two-thirds in Warwickshire, over one-half in Derby and Nottinghamshire, two-fifths in Oxfordshire and nearly one-fifth in Staffordshire; it was lowest in the south-east of England, in particular in Sussex and Kent, Darby, p. 173.
Domesday Book. These districts were well wooded and ores similar to those exploited in the Northampton sands were available in the south of the county. Norman influence in the creation of this new area of production is indicated by the seven Frenchmen (francigeni) referred to as holding land and three iron-forges at Stow in Well. Iron-working in Lincolnshire, however, was apparently not of long duration, as no reference to it is made in a survey compiled in the years 1115 to 1118.1

Stow in Well belonged to the Bishop of Lincoln who was one of the King’s Norman followers. The only other ecclesiastical estates on which iron-working was being carried on at the time when Domesday Book was compiled, were those belonging to the Benedictine Abbey of Glastonbury in Somerset, distinguished in the Anglo-Saxon period by St. Dunstan’s abbotship. The manors of the abbey formed one huge estate in the centre of the county, comprising an eighth of the whole, with a population amounting to a tenth of the total population of Somerset. It is quite consistent with the wealth of the abbey and the extent of the property that the manufacture of iron there was considerable. The number of smiths working at Glastonbury exceeded those in the city of Hereford (eight compared with six). Iron was worked at Glastonbury but evidently not smelted, since no ironstone could be found in the lias of the Polden Hills near Glastonbury. The smiths probably obtained their iron from the manor of Pucklechurch, Gloucestershire, which belonged to Glastonbury Abbey. Within the manor haematite ore was available. The not inconsiderable number of ninety blooms produced there which was more than at any other place, suggests extensive activity.2

All the other ironworks referred to in Domesday Book were on land belonging to the King’s baronial followers. The manor of Ditchling in Sussex, the only ironworks on record in the Weald in 1086, was the property of Robert, Count of Mortain, in Normandy, King William’s half-brother.3 The development of iron-working on the estates of the Norman nobility is even more marked in the west and the north. In Somerset the mills at Lexworthy, referred to above, were erected on the estates of Roger de Courselles. Alvington, south-west of Lydney in Gloucestershire, from which a considerable amount of blooms of iron was rendered in 1086, was held by Thurston, son of Rolf, a baron from Normandy. In the north of England, which had suffered most from the effects of Norman plundering and devastation, the first evidence of the mining and working of iron also comes from the estates of Norman nobles. Hessle, at which it is recorded that there were six iron-workers in 1086, was on the estate of Ilbert de Lacy (Lassi in Normandy) who

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had compact holdings in south Yorkshire with the castle of Pontefract as their centre. The iron mine near Rhuddlan (now in Flintshire) was possessed in equal shares by two Norman nobles, Hugh, under whose lordship the whole of Cheshire was placed, and his cousin Robert of Rhuddlan, the conqueror of the Welsh kingdom of Gwynedd in the north of Wales.¹

Ironworks recorded at a later date were also first possessed by lay owners of the Norman nobility before they were granted to monastic orders which is quite significant in the region of the Forest of Dean and the adjoining valley of the River Wye. Early in the twelfth century Baderon of Monmouth had one forge at Osbaston, west of Monmouth, and three others on the River Wye, near Monmouth, which he gave to the Benedictine Priory of Monmouth, but the forge at Osbaston he kept in his own possession.² Milo, Earl of Hereford, who died in 1143, owned a forge near St. Briavels in the Forest of Dean which he granted to one of the earliest Cistercian Abbeys in England founded at Tintern on the Wye in 1131.³ On the other side of the Forest, Milo’s son Roger bestowed a forge he owned at Edland on the Cistercian Abbey of Flaxley.⁴

The acquisition of ironworks by Cistercian Abbeys such as Flaxley and Tintern, almost immediately after their foundation, reveals an eagerness to secure mining rights and to develop the production of iron, which is equally characteristic of the Cistercian houses founded in the same period in the north of England. There, too, some of the mines and ironworks had belonged to lay owners before the Order acquired them.⁵

THE COMING OF THE CISTERCIANS

At the time of their first entry into England in 1128 the Cistercians were no obscure order but one whose success was already assured on the Continent. Founded at Citeaux in Burgundy in 1098 the order extended its houses from France to Portugal, Spain, North Italy, and Germany in its first thirty years of activity.⁶ In England the Cistercians settled

¹ Stenton, pp. 607, 619, 622, 624; see also Map II.
² About Baderon see VCH, Herefordshire, vol. i, p. 277, and H. R. Schubert, 'Medieval Ironworks at Monmouth and Osbaston', Jo., vol. 161, p. 326. Near Monmouth iron must have been made quite early, since Wihenc, the Norman lord of Monmouth, gave all his tithe of iron from the lands of his tenants to the Abbey of St. Florent, near Saumur, with the permission of William the Conqueror given before 1086, Cal. of Documents preserved in France, pp. 406–407. London, 1899.
³ The forge must have been in operation quite early in the century, as in the documents concerning the grant, reference is made to the forge being in existence in the time of Henry I who reigned from 1100 to 1135. Cal. of the Charter Rolls, vol. iii, pp. 88, 96.
⁴ The grant was confirmed between 1151 and 1154. VCH, Gloucestershire, vol. ii, pp. 93–94.
⁵ See Map V.
Destruction of the Industry in the Norman Period

first in Surrey. The cultivated south, however, did not offer sufficient scope for the restless energy of the monks. It was among the lonely dales and the wild moorlands of Yorkshire and in the valleys of Wales, that they were really able to put into practice the spirit which animated the founders of Citeaux. Soon they were endowed with much forest and waste land by the great and small landowners in the districts of their first settlements.

It is rather perplexing that during the nineteen years of anarchy and internal wars which characterised the reign of Stephen, the last Norman king, a great number of religious foundations were established in the country. A contemporary chronicler was not far from the truth when he said that a greater number of monasteries were founded during the reign of Stephen (1135–1154) than in the preceding hundred years. The Cistercian monastery of Boxley in Kent, for instance, was founded by a captain of Stephen's mercenaries in 1149 at the very height of the civil war. The benefactions made by these rough and often brutal soldiers who endowed monasteries with the proceeds of their plunderings, were perhaps to atone for the hardships they had imposed upon peace-loving people.¹

The founding of Cistercian Abbeys in the north proceeded rapidly in the second quarter of the twelfth century. In 1127, the abbey of Furness in Lancashire, which afterwards joined the Cistercian order, was founded and endowed by Stephen, Earl of Boulogne and Mortain, who afterwards became king. In 1132 the great abbeys of Rievaulx and Fountains, both in Yorkshire, followed. Within a few years after its foundation Rievaulx had become the most celebrated monastery in England. Before the first half of the century had passed, all the great houses of the order in the north of England were established. The Abbeys numbered about fifty by the year 1152 at which date a decree was issued by Citeaux prohibiting further foundations of Cistercian Abbeys. A very few were, however, established in England afterwards.

The Cistercians established in the north lost no time in acquiring mines and erecting ironworks wherever ore deposits were available. A typical example is the acquisition of mining rights by the monks who founded the Abbey of Byland. Twelve Cistercian monks with their Abbot, from Furness in Lancashire, settled first at Calder in Yorkshire in 1135, but four years later their monastery was demolished by a raid of the Scots. So they decided to go to York. When on their way they approached the castle of Thirsk. The monks, by their poverty-stricken appearance, raised the compassion of Gundreda, the mother of Roger de Mowbray. The noble lady became their first benefactress, gave them temporary shelter and promised them a new home. After they had found themselves a place at Old Byland in 1143, Gundreda granted them the right to mine iron and lead in the district of Nidderdale

¹ A. L. Poole, From Domesday Book to Magna Carta, pp. 188–189. Oxford, 1931.
VII Anglo-Saxon smith working. From the British Museum; Cotton MS., Claudius B IV, fol. 10.

VIII On the left, a dome-shaped shield boss ending above with a point; on the right a conical shield boss with point and framework. By courtesy of the Ashmolean and Dover Museums.
IX  Bell of St. Cailleach in its shrine, by courtesy of the British Museum, London.

X  Early medieval draw-plate, by courtesy of the Verein Deutscher Eisenhüttenleute, Düsseldorf.
between Knaresborough and Richmond, which grant was confirmed by all her descendants until 1345.¹

The greatest contribution to the rise of the British iron industry made by the Cistercian abbeys in the north of England was the systematic exploitation of the clay ironstones. As early as in the last phase of the Norman era, a number of mines and forges were worked in immediate proximity to the celebrated Tankersley ironstone deposits, which extended from an area in the West Riding between Sheffield and Rotherham northwards to Tankersley, Barnsley and farther north towards the River Calder and Ardsley (Map V). The iron industry based on these ores remained of primary importance through many centuries. Although it was not an entirely new industry which the Cistercians created in those parts of the country, they greatly extended and intensified the work begun on a small scale by previous lay owners. The industry of the Cistercians was subserved by the abundance of wood for charcoal that they found in the extensive forestland.

FORESTS AND WOOD SUPPLY

Throughout the Norman period England was still covered with forests. A great part of the country's woodlands was reserved by the so-called Forest Law of William the Conqueror as royal preserves. The reserving of forests as hunting grounds for the King had started before the Norman Conquest, but William enlarged the borders of King Edward's forests and created new ones, such as the New Forest in Hampshire. The result was that in the twelfth century almost one-third of the whole acreage of England belonged to the king. These forests were not continuous tracts of woodland. They contained a nucleus of wood and sometimes large tracts of wooded territory, but also hamlets with their settlements and cultivated lands. Although the new forest legislation was mainly designed to protect the king's deer, it had incidentally a beneficial effect in preserving the country's timber resources, since it severely restricted the right to cut wood and clear forest ground for habitation, which had been extensively done in the Anglo-Saxon period.²

The Anglo-Norman forest legislation, in preventing further deforestation, produced a gradual accumulation of wood resources for future use. In the New Forest charcoal burners were active as early as in 1100, at which date one of them found the body of William Rufus, the Conqueror's son and successor who had met with a mysterious death while hunting in the forest. The wood of dead branches and of fallen trees was abundant in the medieval forests and woods and is constantly

Destruction of the Industry in the Norman Period

referred to in documents and accounts. The large quantities of this wood lying on the ground and liable to decay could hardly be better utilised than by charcoal-burning, and charcoal was most lucrative when sold for industrial purposes. In this way the abundance of wood practically called for a revival of the iron industry. Probably it was a surplus of windfallen wood that started a revival of iron-working by itinerant smiths in the royal Forest of Rockingham, in Nottinghamshire, at the very end of the Norman period. Between 1168 and 1172 thirteen different forges which had been erected some time earlier, were in operation within the boundaries of the forest. ¹

Possibly in other royal forests also a surplus of wood was the cause of increased activity in iron-smelting. In Buckinghamshire references were made to smithies (fabricae) from 1158 to 1162. On the west side of the county and extending well into Oxfordshire the royal forest of Bernwood had ample stores of wood at the time of Domesday Book and later. Place-names such as 'Colleputtes', i.e. pits for charcoal-making, and 'Smythedene' recorded more than a century later were reminiscent of former iron-working. A reference to charcoal-burners, smiths and iron in Shropshire in the years 1164 and 1165 may also suggest that iron-working was taken up at the close of the Norman period in the county, which was well wooded. ²

CHARACTER OF THE INDUSTRY

A characteristic feature of the iron industry in the early Norman as much as in the late Saxon period is production mainly by local smiths for local requirements, using primitive bowl-furnaces. This is shown by the many customary rents referred to in Domesday Book and paid in blooms of iron in iron-producing districts. The payment of customary rents in the form of iron in England is not unique. It has a parallel on the Continent where according to the rentals of certain monasteries, such as Lorsch in Hessen and the well-known Abbey of Fulda, the foundation of St. Boniface, rents were paid in iron. Both had vast possessions dispersed all over West Germany, and both received rents in the form of iron blooms from tenants in mining regions. The amount of iron paid by each tenant varied according to the extent of the land he rented. The blooms of iron were only a part of the rent, the rest being paid in sheep and hens. ³ In those early days rents were paid mainly in products of the soil and in cattle; not in money. The render of iron which in the eleventh century occurred principally in Gloucestershire and Somerset continued in the south-west of England still

¹ The Great Roll of the Pipe, Henry II, vol. xiii, p. 76; vol. xv, p. 22; vol. xvi, p. 46; vol. xviii, p. 36.
in the early fourteenth century. At Chillerton, in Hampshire, five pieces of iron were rendered in addition to wax in 1271-2, and in Newton the same number. In the manor of Chedzoy, Somerset, the practice of paying in iron ‘slabbes’ continued as late as the 1330’s.¹

The tenants who paid such rents may have been farmers and peasants occupied with agricultural work in summer, while in winter they tried to get iron sufficient to make the implements they needed for use in their homes and on the land. To produce the iron, however, they would have needed a skilled ironworker; it is not likely that the peasants themselves were able to do such work, which has always required special skill and dexterity from the prehistoric period onwards. Such large amounts as the ninety blooms delivered from Pucklechurch, in the south-east of Gloucestershire, could hardly have been smelted and worked up by the peasants of the district without the help of professional ironworkers. So it is probable that smelters and smiths worked the iron for tenants of the land on which the ore cropped out. If the demand of one farmstead was satisfied, or the ore found on the land exhausted, the smith would go to work at another place. The activity of such an ironworker had all the characteristics of the work done by the so-called itinerant smiths frequently referred to in documents of the two subsequent centuries (see chapter 8). A part of the iron produced, however, went to blacksmiths working for larger communities such as villages, manors, and towns like Gloucester and Hereford, in which a fair number of smiths is on record, or for a monastery like Glastonbury.

The above-described state of affairs was not confined to England, but was quite common in iron-producing regions of the Continent. There is, however, one item recorded in Domesday Book which is unique, and which may be of importance in the history of iron. This is the reference to two mills rendering two blooms of iron each as their customary rents.² None of the Continental sources quoted above³ refers to any mill from which a payment was made in iron. Therefore it seems possible that the two mills, situated at Lexworthy in Enmore, west of Bridgwater in Somerset, were proper iron mills, i.e. ironworks in which a current of water was applied as motive power for a wheel moving the bellows. Water-driven corn mills were no novelty in those days; in Domesday Book more than five thousand are mentioned,⁴ and quite a simple contrivance would serve for blast-production with the aid of a water wheel. The evidence supplied by Domesday Book, however, is not sufficiently concrete to justify a definite conclusion.⁵

² ‘II molini redd(entes) II plumbas ferri’ *VCH, Somerset*, vol. i, p. 472.
⁵ Johanssen, p. 93, is quite sure that the mills were ironworks (‘müssen Eisenhütten gewesen sein’). All English historians, however, have been too cautious to make any definite pro-
Although the iron produced in the period under review was mainly absorbed by local requirements there is evidence of some trade beyond the local area of production. Some of the iron coming from the forges at Monmouth and Osbaston in the early twelfth century, was purchased by merchants who resold it at a profit,\(^1\) probably to the smiths in neighbouring towns such as Gloucester and Hereford.

**THE ANGLO-NORMAN SMITH AND HIS WORK**

In addition to the smiths who supplied the needs of rural communities and of castles, there were artisans working up the iron into articles for common use and operating in the towns. Towns gradually gained importance in the Norman period although their total population in 1066 probably was not more than a tenth of that of the country as a whole.

The rods or bars of ductile iron rendered by the city of Gloucester at this time were particularly suitable for forging by the smith into various objects. The ductility of the iron made it possible to elongate the rod without cracking it under the blows of the hammer. The rods were intended to be forged into ship-nails. Such ductile iron however was equally suitable for other objects much in demand in the period, such as the rings for the flexible armour or chain mail which after the Norman Conquest came in use to protect the body of the mounted knight. The rings were made by the smith who with the aid of a hammer elongated and rounded the iron rod, which was thus transformed into a coarse wire of a somewhat smaller diameter than the original rod. The wire was then cut into pieces, each of which was bent into the shape of a ring. The rings thus made were interlaced and the ends welded together. Far into the eleventh century the mail-shirt made from the rings had short sleeves, which gave no protection to the lower arm, but some time before 1100 A.D. a change took place. The sleeves were lengthened down to the wrist to protect the lower arm, but the longer the ring-mail, the heavier it became. To prevent it from growing so heavy as to fatigue the wearer, rings of more delicate sizes were required. They afforded a further advantage. The finer the network of interlinked rings, the more it protected the body against arrows.\(^2\)


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For rings of more delicate sizes the coarse wire, produced by the hammer alone, was not fine enough and a wire less massy and smaller in sectional diameter had to be substituted. To make this finer wire, a draw-plate or wortle was required, through the holes of which the coarse wire was forced. It is very probable that the increasing demand for flexible chain-mail in the Norman period led to the use of a draw-plate, since draw-plates were known at this time both in Germany and in the Scandinavian countries, the original home of the Normans. Theophilus, a German monk of the eleventh century, described draw-plates with three and with four rows of drawing-holes. A plate for wire-drawing with three rows dating from the age of the Vikings (800-1050 A.D.) was found in Norway (reproduced on Pl. X).¹

In the Early Middle Ages nails and spikes for fastening tiles and slates on to roofs and, perhaps, one or two nails for the door latch, had been the only iron used in ordinary buildings.² Larger quantities were required for the fortifications of the castles and towns which began to be built shortly after the Conquest and continued to be built throughout the whole period. Iron was used mainly for securing the entrances. The principal entrances through the walls were flanked by towers with small windows strongly barred with iron. The gates, made of stout oak, required iron hinges, locks, bolts and bars. Postern-gates made either of wood clamped and studded with iron, or of iron bars crossing rectangularly, were used extensively on the Welsh and Scottish borders. The manufacture of gates made entirely of iron bars required much skill in forging so as to make it impossible to wrench the bars asunder. According to Gardner ‘while the bars were being welded, one half were passed through the verticals and the remainder through the horizontals’. Iron was used also for drawbridges, the timbers of which were fastened together with iron straps, and for the levers, cranks, and chains which operated the bridge.³

The most elaborate work produced by the Anglo-Norman smith was the grilles which encased tombs and the shrines of saints or enclosed choir and side chapels. The grilles required strength for protection against intruders, combined with translucency which allowed spectators to look through. Such a combination could best be obtained by the use of iron. The earliest example known is the grille in Winchester Cathedral which formerly protected St. Swithin’s shrine and which probably dates from 1093. It is now reduced to a few fragments, but a reproduction in wrought iron of a part is in the Victoria and Albert Museum (see Pl. XI).

The Winchester grille is constructed of C-shaped scrolls grouped in

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...threes. Two bundles, each consisting of three scrolls, are joined back to back by iron ties, the interstices being filled with smaller scrolls. In a part of the grille the ends of the larger scrolls are forged each into a cinquefoil cluster, i.e. a leaf-shaped bunch of five leaflets. In the remainder of the grille the bunches consist of three leaflets. As the bunches are made of six or more thicknesses of iron bound together, the heavy effect which they would otherwise have produced is avoided by thinning them down and welding. By these means greater transparency without sacrifice of strength is achieved.¹

To sum up: the Norman era of English history was a period of transition for the iron industry. Despite terrific impediments caused by repeated waves of internal war and unrest, some progress undoubtedly was made. The most significant was the expansion in the north which commenced in the last phase of the Norman regime and opened up new mining fields with ore resources hitherto neglected or not worked at all. Their exploitation however did not come into full effect until later. Technical progress was not lacking either. The introduction of mechanical devices such as the draw-plate for wire-drawing most probably belongs to this period; as also the first tentative steps in the direction of mechanical blast-production for the smelting of iron by using the current of small streams as motive power. The high standard of the smith’s work is attested by achievements in the sphere of decorative art, such as the St. Swithin grille. Compared with the state of affairs in the twenty years between the Conquest and the Domesday Book, by 1154 the area of iron-mining and working had expanded considerably in various parts of the country, particularly in the north. Wood resources were more than sufficient for the needs of the time. All in all, it can be said that at the close of the Norman era the foundations for further expansion and prosperity of the iron industry were laid. The initial stage of a development was reached which came into full flower in the following period, the Age of the Medieval Renaissance in England.

¹ Gardner, vol. 1, p. 72.
CHAPTER VI

RISE AND DECLINE IN THE MEDIEVAL RENAISSANCE

(1154–1348)

THE MEDIEVAL RENAISSANCE

The period from the late twelfth to the end of the thirteenth century was one of the most brilliant in the cultural and intellectual history of Europe. It was the age of the building of universities and great cathedrals. Such magnificent creations were rendered possible by, and based upon, a growth in wealth and an increase in material prosperity which affected the whole of central and western Europe. With the ascent to the throne of Henry Plantagenet, Count of Anjou, as Henry II (1154–89) England entered at last upon a period of relative peace. Henry as ruler of an empire extending from the Pyrenees to the Cheviot hills was powerful enough to control the unruly English baronage more effectively than had his Norman predecessors.

The pacification of the country after the turbulent century which had followed the Norman Conquest made possible an unprecedented expansion of agrarian and industrial production paralleled by a growth of population. Towns sprang up everywhere and grew rapidly in this period. The crusades opened a new field to the merchants. Traffic was extended, and with commerce came wealth. In agriculture and industry the demand for iron increased more than ever before. It was required for farm implements, and tools for the crafts, for anchors and nails in shipbuilding, for armour and weapons, and also for constructional purposes in building.¹

The two centuries between the crowning of Henry II in 1154 and the Great Plague of 1348 became the most active period in the early history of the English iron industry.

¹ CEH, vol. ii, pp. 436 and 439.
INCREASING DEMAND FOR IRON

In the thirteenth century the importance of iron to the civilised world began to be generally appreciated. This is reflected in a medieval encyclopaedia written around 1240 by Bartholomew, an Englishman by birth and a member of the Franciscan order, who lived for a long time in Paris and Saxony and was a celebrity of international repute. He called the use of iron 'more needful to men than the use of gold'. 'Without iron,' he went on, 'the commonalty be not sure against enemies; without dread of iron the common right is not governed; with iron innocent men are defended; and foolhardiness of wicked men is chastised with dread of iron. And well-nigh no handiwork is wrought without iron: no field is eared without iron, neither tilling craft used, nor building builded without iron.'

This was no mere eulogy. Bartholomew clearly delineates the spheres of human activity in which iron was indispensable in his days. Expansion of the cultivated areas accompanied the growing prosperity of the monastic orders in the early thirteenth century. The crafts had expanded under the Normans and were still making progress in Bartholomew's lifetime; armaments for war abroad and for keeping the peace at home were a necessity in those days.

The demand for iron from which to manufacture arms seems to have increased from the late twelfth century onwards. The Pipe Rolls, which contained the accounts of the whole revenues of the Crown, abound in references to large quantities of bar iron and manufactured goods delivered at the kings' request, for the equipment of the army and navy. Military expeditions to Ireland, wars in France, and crusades were the great consumers of iron. The largest supplies came from the city of Gloucester which was the commercial centre of the iron-producing region of the Forest of Dean and neighbourhood. A second centre of armament supply was the Palatinate of Durham. Arrows with iron heads, quarrels and horseshoes were produced in large quantities for the equipment of the army; and nails, bars, and anchors for the royal ships. Nails were also produced both for repairs and for new buildings, including royal castles and hunting lodges. Spades, hatchets and pick-axes were required in the work connected with building, and also for fortifications and for undermining the walls of besieged fortresses.

The demand for arms stimulated production in regions beyond the principal centres of iron-making, and in the last quarter of the thirteenth century production of arms was extended to small local centres of iron-making all over the country. This was due to the arming of the popula-

2 VCH, Gloucestershire, vol. ii, pp. 216-217 — VCH, Durham, vol. ii, p. 353 — Quarrels were missiles analogous in type to the bolt of the crossbow; they were winged, sometimes with iron and brass, sometimes with feathers, EHR, vol. xxvi, p. 386. London, 1911.
tion to enable them to keep the peace and protect themselves against robbers and criminals made obligatory in the reign of Edward I, whose magnificent work as a legislator earned him the title of the ‘English Justinian’. His Statute of Winchester of 1285 decreed that the whole male population of the realm between the ages of fifteen and sixty should carry arms. This stringent measure was taken because of the lawlessness prevailing in many districts, or, as it was worded in the preamble to the statute, because ‘from day to day robberies, murders, burnings and thefts be more often used than they have been heretofore’.¹

Fig. 13. Diagram showing iron tie-bars of the interior in Westminster Abbey.
From Lethaby, p. 140, Fig. 59.

Iron was also required in increasing quantities for the great building operations which in the later years of Henry II’s reign absorbed much of the King’s attention and money, and which were continued by his successors. In the years 1171 and 1172 large consignments of nails were dispatched from Gloucester to Winchester for the repair of the royal palace. Under Henry’s successors iron was obtained from Gloucestershire when work was in progress on any of the royal houses. In 1251,

¹Statute, vol. 1, p. 96.
Map III. The Iron industry in England, Scotland and Wales between 1250 and 1300.

I  Sussex (for particulars see Map I)
II Buckinghamshire
III Somerset and Wiltshire
IV Forest of Dean and Wye Valley (for particulars see Map IV)
V  South Wales
VI North Wales
VII South Cheshire
VIII Derbyshire
IX Staffordshire
X  Northamptonshire
XI Sheffield area
XII Barnsley, Bingley, Leeds (for particulars see Map V)
XIII Forest of Knaresborough, Spofforth, Nidderdale
XIV Richmondshire
XV Bowland, Rochdale, Skipton
XVI North Lancashire
XVII Cumberland
XVIII Cleveland and Forest of Pickering
XIX Durham
XX Northumberland
XXI Scotland
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e.g., iron was sent from Gloucester to the King’s works at Freemantle, in Kingsclere, Hampshire, and iron pegs to shut the glass windows at the royal castle of Clarendon, in Wiltshire.  

A novelty was the use of iron for constructional purposes which commenced in the late twelfth century, e.g. at the rebuilding of Canterbury Cathedral after its destruction by fire in 1174. In the work of William of Sens who carried on the re-building until he was disabled by accident in 1178, the arcade around the eastern transept is stayed with iron. An early example of the actual incorporation of iron as a part of the building is to be seen at Westminster Abbey. The Abbey as we see it at present, is mainly the design of Henry III, the ‘greatest builder and the greatest patron of the arts who has ever occupied the throne of England’. The iron tie-bars used are part of the first construction which was begun in 1245. The ties are attached by hooks, but several were built into the work directly. There are not only continuous longitudinal ties to the arcades, but others passing across the aisles, so that in some perspectives there are four or five bars crossing at different angles. In the Chapterhouse the central pillar was provided with an umbrella-like arrangement of iron rods from the capital to the vaulting ribs, but only the hooks of the rods remain.

At Salisbury Cathedral the stonework at the base of the spire was strengthened in the fourteenth century by inserting wrought iron bars 1 1/4 inches to 2 1/4 inches square. On the inside these bars, set flush with the stonework, are still in good condition.

THE AREA OF PRODUCTION

The increased demand for iron led to expansion of the working area in the various existing regions of mining and smelting. The principal region was in the south-west of the country with the Forest of Dean and the adjoining valley of the River Wye as a centre (No. IV, on Map III).

South-west

The large consignments of iron sent frequently from Gloucestershire show the importance of the regional iron industry which made the Forest of Dean by far the greatest iron-working district in medieval Britain. This was recognised and appreciated by contemporary writers

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5 The various districts of iron-working are shown Map III, Nos. I–XXI (above pp. 96–97).
as early as the twelfth century. Giraldus Cambrensis (i.e. of Wales) in his itinerary through Gloucestershire and Wales of 1188, described the Forest as 'abounding with iron and deer', and the city of Gloucester as 'celebrated for its iron manufactories'.

The king's forges, as well as numerous forges in private hands, were in operation as early as in the reign of Henry II (1154–89). In the first half of the following century the Crown vacillated between the desire for profit from the forges and reluctance to sacrifice the large quantities of wood they consumed. In theory no forge was permitted to operate without a royal licence, but in practice this rule was mostly

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not observed. New forges were established and wood taken from the Forest without permission. Eventually the destruction of timber became so serious that in 1217 all forges in private hands, with the exception of six, were ordered to be closed down; but it is evident that the order was either ignored or soon afterwards cancelled, seeing that before the middle of the thirteenth century between twenty-five and thirty forges were being worked in the Forest. The number increased to at least forty-three in 1270 and sixty in 1282, but diminished a few years later.

Map V. Mining and smelting of clay ironstone in south-west Yorkshire in the twelfth and thirteenth centuries: for Nos. 1–15 see pp. 102–103.
<table>
<thead>
<tr>
<th>No. on map</th>
<th>Date</th>
<th>Place</th>
<th>Designation of Works</th>
<th>Owner</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>about 1219 about 1166</td>
<td><em>Harden, at the confluence of Hardenbeck and the river Air new place on Harden Broc</em></td>
<td>one forge</td>
<td>land for the erection of forges</td>
<td><em>ECH</em>, vol. iii, pp. 341–2, 344–6.</td>
</tr>
<tr>
<td>9</td>
<td>late twelfth—end of thirteenth century</td>
<td><em>Bentley</em></td>
<td>forge</td>
<td>Cistercian Abbey of Byland</td>
<td></td>
</tr>
</tbody>
</table>
to forty-five, which may have been the result of a new royal measure prompted by the damage done to the Forest.

Iron-working in the south-west of England which centred in the Forest of Dean, extended far beyond the boundaries of Gloucestershire, into Wales and parts of Somerset and Wiltshire (Map III, No. III). In 1235 the Bishop of Bath was granted a licence to mine for both lead and iron in the royal forest of Mendip, in the neighbourhood of Charterhouse-on-Mendip in Somerset. In the royal forest of Chippenham in Wiltshire the mining of iron and its working in itinerant forges started in 1229 and continued until late in the century.

That iron was mined and manufactured in Wales shortly after 1200 may be inferred from the particular skill of the Welsh in the manufacture of weapons of war, which were sent to various English counties such as Somerset and Northamptonshire. There is no reliable evidence of work in North Wales (Map III, No. VI) earlier than 1301. There was mining in the south, however, particularly in Glamorgan and in the
XI The Victoria and Albert Museum reconstruction of The St. Swithin Grille in Winchester Cathedral.

XII The helm of Sir Richard Pembroke, from Hereford Cathedral, by courtesy of the Librarian.
XIII  (A) Trench, Scowles near Coleford.  (B) Tunnelling, Scowles near Bream.
By courtesy of Mr. I. Cohen, Hereford.

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adjacent part of Monmouthshire (No. V), the earliest record being of 1227 at which date mines of silver, lead, and iron are said to have been found in Glamorgan. In the second half of the century mining rights granted to the Cistercian Abbeys of Margam (1253) and Neath, in Glamorgan, are on record. Shortly after 1300 activity increased. The output of charcoal increased considerably and charcoal-burning developed into an industry of more than local importance. Iron-miners were called to Glamorgan from the Forest of Dean, and they may well have improved mining in south Wales. In any case, the mining field was extended into the county of Brecknock, in which the mining of iron is recorded first in 1336.

The North-west

A second centre of iron-working evolved in the north-west of England. Starting in the final phase of the Norman period, it developed first in a district extending roughly between Sheffield in the south, and Bingley and Leeds in the north (Maps V, and III, Nos. XI and XII). This was to exploit the clay ironstones of the coal-measures and their systematic exploitation marked an important stage in the progress of iron-working in England. The coalfields of Yorkshire and of the Midland counties such as Derbyshire, Shropshire, and Staffordshire were rich in similar ores. Though these ores were already known to lay owners of mines and of small ironworks in Yorkshire, their exploitation on a large scale did not commence before the Cistercians took an active part in it. They began upon the best ore deposits in the south-west of Yorkshire, the Tankersley and the Black Bed ironstones.

The Tankersley ironstone which occurs at a distance of ten to twenty-five feet above the Flockton coal was worked in many places along its outcrop from the vicinity of Ardsley to as far south as Sheffield. Its thickness varies, but on an average it is about one foot. The seam of ironstone which is known in the Low Moor district as the Black Bed

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3 M. L. Bazeley, 'The Forest of Dean in its Relations with the Crown during the Twelfth and Thirteenth Centuries', Tr. of the Bristol and Gloucestershire Archaeological Society, vol. xxxii, pp. 236, 266. Bristol, 1910 — The position of the forges which are enumerated in the Forest Proceedings of about 1250 and of 1270 (PRO, Exchequer KR, Bundle 1, No. 25, and Treasury of the Receipt, No. 28), is shown on Map IV.


1—H.L.S.

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ironstone, covers a much smaller area between Colnebridge and Rastrick. Apart from these, bands of nodular ironstones which occur at several horizons in the Coal Measures of the district were worked in the Middle Ages. Around 1200 many of the great Cistercian abbeys in the north had secured mining rights and had erected their forges near the outcrops of the seams.  

In the thirteenth century, in which the iron industry of this region achieved its greatest development and extension, it constituted a rival to the old established industry of the Forest of Dean, but did not become its equal. The brown haematites mined in the Forest were of superior quality mainly because they contained less impurities, e.g. phosphoric acid, of which not more than a fraction is present in the Forest ores, whilst there is usually up to 1% and sometimes more in clay ironstones. On the other hand, the presence of a higher percentage of manganese gave the clay ironstones one distinct advantage over the Forest ores because this made them more suitable for the production of a steely iron.

Mining and smelting appear to have been transferred from Ardsley to the immediate vicinity of Leeds by the Cistercians of Kirkstall very early in the thirteenth century. The forge at Kirkstall (Leeds) was erected shortly after 1200. A few decades later they exploited iron ore between their granges at Roundhay and Seacroft. At both these places and at Rothwell considerable activity developed towards the close of the century and the beginning of the fourteenth when an additional forge was being operated in Scoles Park.

North of Leeds, at Spofforth and in the Forest of Knaresborough, iron-working was conducted on a lay-owned property, and on the royal desmesne (No. XIII). At Spofforth, held by the Percy’s, a noble family of Norman descent, two forges were being worked in 1258. In the royal forest of Knaresborough forges are mentioned as early as 1206-7, the largest being at Blubberhouses (first referred to in 1227). Towards the end of the century the forest was the seat of a very active iron industry with four large works in operation and, in addition, some small forges of lorimers and nailsmiths in the immediate neighbourhood.

In Nidderdale, north of Knaresborough forest, the two great Cister-

1 W. W. Smyth, *The Iron Ores of Britain*, Part i, p. 36. London, 1856 — For the distribution of the ironworks see Map V.

2 *Analyses Percy*, pp. 207, 211 et seq. — Forest of Dean iron was greatly appreciated because of its tenacity, and for this reason much sought after. In 1252-53 e.g., four tons of 'tough' iron from Gloucester were purchased for the works at Westminster Abbey, Salzman, *Building*, loc. cit., p. 286.


cian houses of Byland and Fountains had the right to mine iron and lead ores after 1143. Fountains had forges from the end of the century onwards, one at Dacre and a second higher up the valley.¹

Farther to the north, a few ironworks were operated in Richmondshire (Map III, No. XIV), in the Forest of Wensleydale, which was once the most important part of the large forest district of Richmond; in Colsterdale and in Lunedale, the most remote part of the West Riding. On the western borders of Yorkshire forges were working in the Chases of Bowland and Skipton (No. XV). The Priory of Bolton had a forge, mentioned from 1294 onwards.²

Of much greater importance than the small ironworks scattered all over the north-west of Yorkshire was the exploitation and working up in Cumberland and Lancashire of the red haematite ores, the richest ores in the whole country. In Cumberland (No. XVII) it was in the area of Egremont, famous as an industrial centre in subsequent centuries, that the mining and working of haematite started some time after 1150. A prominent part in the development of the industry was taken by the Cistercian abbey of Home Cultram, situated between Carlisle and the Solway.³

In the peninsula of Furness, in the northern part of Lancashire (No. XVI) another Cistercian house lead the industry, namely the abbey of Furness which exploited iron ores in Lower Furness. The first grant of mining rights is dated 1235. The majority of the other grants are undated but apparently they belong to the beginning of the thirteenth century. The mining and working of haematite ores proved to be a valuable asset in the economy of the Abbey, for in 1292 the income from mines greatly exceeded any of its other receipts and amounted to one sixth of the total income from temporalities. How greatly Furness iron was valued is shown by the fact that raiding Scots in 1316 carried off all the iron they could find. The Priories of Conishead, in Furness, and of Cartmel, in Lancashire, were also active in working red haematites. The richness of the slags found in Rossendale points to the use of haematites probably obtained from Furness.⁴

The North-east
Iron-working in the Forest of Pickering, west of Scarborough, and in the Cleveland Hills (Map III, No. XVIII) is on record in the twelfth and thirteenth centuries, in which a fair number of ironworks were operated, mainly small forges. The Lewisham ironworks in Pickering forest, belonging to the noble family of Bolebec, are first referred to in 1207.

¹ VCH, Yorkshire, vol. ii, pp. 344, 352, 368.
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Another nobleman possessed forges in Glasdale, Cleveland, which he gave to the Priory of Guisborough in 1223.¹

Because of the lack of reliable evidence it is hardly possible to assess the extent of medieval iron-working in the county of Durham (No. XIX). Some activity at the close of the twelfth century is on record, since several smiths are referred to in the Boldon Book of 1183, and an iron mine was granted in the same period by Bishop Pudsey of Durham. That the mining and working of iron occurred on a considerable scale throughout the thirteenth century is indicated by the large consignments of iron bars and manufactured goods sent to Chester, London, Portsmouth, Ireland, and Wales. Forges operated within the bishopric were still in existence in the early fourteenth century. In the same period iron-working was carried on in Northumberland, near Alnwick and in the Lordship of Wark in Tindale, which temporarily belonged to the bishop of Durham (No. XX).²

Scotland

In Scotland numerous slag heaps have been found, many of which may be the dumps of medieval ironworks. Only a small number can be dated as medieval, however. At Bonnybridge on the north side of the Antonine Ditch lumps of iron slag point to iron-working, and a sherd discovered among the slags has been ascribed to approximately 1200 A.D. Iron may have been worked even earlier. A tithe of all iron coming to Dunfermline was granted to the Abbey of Dunfermline in 1153, and a tenth of iron was granted to St. Peter’s Hospital in Aberdeen somewhat earlier than 1199, but the iron was not necessarily of native origin. It may have been imported; especially as there is documentary evidence of iron-importing at an even later date. The 26½ cwts. of iron sent to the royal castle of Air in 1264–66 to make bolts for crossbows was definitely imported.³

Remains indicating the greatest iron-working activity of medieval Scotland were found south of Elgin in Morayshire, on lands formerly belonging to the Priory of Pluscarden. In the vicinity of the Priory and also near Melfrhi and Urquhart abundant masses of slag and numerous saucer-shaped pits filled with wood-charcoal were discovered. Tithes of iron and mining rights granted to the Priory are referred to as early as 1233 and 1263.⁴

The Midlands

Apart from Yorkshire, two areas became of great importance for the development of the British iron industry in subsequent centuries: the Midlands, in particular the so-called Black Country in south Staffordshire and adjacent parts of Worcestershire, and the Weald of south-east England.

In the Midlands iron-working mostly developed late compared with other districts. An exception however was the north of Derbyshire (Map III, No. VIII). Shortly after the erection of ironworks at Kimberworth near Sheffield by the Cistercians of Kirkstead, their brethren of Louh Park Abbey in Lincolnshire, started similar works in the woods of Barley (Barlow) between Sheffield and Chesterfield. This was however no new introduction of iron-working into the district, as the grantor Walter de Abbetoft already had forges working. Around 1250 the industry had spread to the High Peak and the Forest of Duffield Frith near Belper and Scarsdale Hundred, so that by that time at least eleven ironworks were being operated in the county. About twenty years later iron was being worked in Cheshire. (Map III, No. VII).1

At about the same time as in Cheshire, the clay ironstone deposits of the coalfields were being exploited in north and south Staffordshire and in Worcestershire (No. IX). At the close of the thirteenth century the main concentration of iron-working was in the Black Country, around Dudley and Walsall. In the manor of Sedgley, west of Dudley, Roger de Somery possessed an iron mine and two ‘great smithies’ (grosse fabricae), works somewhat larger than the average forge.2

Iron-working, recorded in this region from the close of the Norman period, still continued in the Forest of Rockingham (No. X) on a small scale, and also in Bernwood Forest (No. II) which extended from the west of Buckinghamshire into Oxfordshire.3

South-east

In the Weald of Sussex (Map III, No. I) which had been an important area of production in Roman England (Map I), evidence of thirteenth-century iron-working is confined to one place, namely Walesbeech near East Grinstead, the only works in the Weald which is mentioned in

There is no evidence for Ireland, although there is no doubt that some production on a small scale was carried on. The iron referred to in a murage-grant of 1284 may have been imported. PRO, Patent Roll No. 109, membr. 14.

3 BM, Harleian Charter 49 G 51 (undated but ascribed to the thirteenth century), see also VCH, Northamptonshire, vol. ii, p. 306 — For Buckinghamshire, see above p. 88.
Domesday Book (Map II). There may have been more, however, as in 1266 the inhabitants of Lewes were empowered to raise tolls from every cart which came from the Weald laden with iron.\(^1\) The large consignments of iron sent to the Tower of London from 1253 onwards may suggest that it was produced at several places in the Weald. In some instances local manufacture is specifically mentioned.\(^2\) In the early fourteenth century eight forges were in operation in the Weald (Map I), and possibly more, remains of which may well be hidden in the numerous slag heaps in the Wealden area still awaiting excavation.

Two main causes were responsible for the rise of the Wealden iron industry. In the first place, great quantities of wood for charcoal were available which had remained practically unexploited, as iron-working was conducted on a very small scale in the earlier part of the Middle Ages, and a second but not less effective cause was the nearness to London, which meant a readily accessible market in an age in which the use of iron was steadily increasing. Under these favourable conditions an industry gradually developed which began to rival the old established one in the Forest of Dean. In 1226, the bishop of Chichester in west Sussex was advised to order his iron from Gloucester, but by 1300 Sussex iron had won a footing in the London market at the expense of Gloucestershire.\(^3\)

The total number of ironworks in England, Scotland, and Wales in the boom period between 1250 and 1300 was at least 150, as authentically recorded in charters and accounts, and the numerous small forges of lorimers, nailsmiths, and smiths working in towns and villages and also employed at the castles are certainly not included in the figures. The forges of itinerant smelters however should be included in the figures because many of them were allowed to operate throughout the years, e.g. in the Forest of Dean, where they were assessed to annual rents.\(^4\)

Although the records give us a fair idea of the intensity of working and distribution over the various regions, they are not complete. A system of accountancy which classes e.g., iron, fowls and various forest products together, yields no clear inference as to the number of works in the region of Durham. Yet the local industry must have been quite considerable, in view of the quantity of manufactured iron produced for armaments. It also has to be taken into consideration that many of the large number of slag heaps still to be found in Cumberland,

\(^1\) Straker, p. 33.
\(^2\) E.g., in 1252-53, 12,000 nails for the roofs of the castle at Freemantle, Hampshire, to be made within the bailiwick of the Sheriff of Sussex ("feri facias in balliva tua") PRO, Liberale Rolls, No. 29 — In 1275, 406 iron wedges or pegs collected by a royal servant who was sent to the Weald for this purpose, and in 1278 a total of 343 wedges made in the Weald (factos in Waldis) 100 of which were bought from one particular smith in the Weald ("cuidam fabro in Waldis"), PRO, Exchequer various accounts, Bundle 467, No. 7(3) and 7(7). See also Straker, p. 33, and Salzman, English Trade in the Middle Ages, p. 24, Oxford, 1931.


Lancashire, the Weald, Scotland and elsewhere, may conceal the remains of medieval ironworks as yet undiscovered. So altogether a figure of about 350 works may safely be assumed.

OUTPUT, TRADE, AND IMPORT

The average output of the English forge between 1330 and 1354 was 2½ tons per year.1 As a decline set in after 1300, we may assume a higher figure, say an average annual production of 3 tons per works, for the preceding boom period. On this basis the total annual output of all the ironworks, large and small, including both those working during the major part of the year and those working for short periods only, would be about 900 tons. No figures from iron-producing regions outside Britain are available for comparison, apart from Styria, and even here the figures are only conjectural, though it seems to be the case that the annual output of all the works operated in Styria in 1300 and later never exceeded 2000 tons.2 Iron and steel produced in Styria from ores much better than the majority of British ores was of the highest repute. It was in great demand in the Middle Ages and long after, which naturally stimulated production; but even if the output of Styria is regarded as a regional maximum in medieval Europe, an annual output of 900 tons still remains a low figure for a large area such as England, Scotland and Wales together. It makes it very doubtful, whether production even at its maximum was nearly sufficient to meet the needs of the country.

Evidence of internal trade in iron is not lacking. The London market absorbed a considerable proportion of the iron made in the Weald.3 Iron bought at Derby fair in 1278 was sent to Rockingham, and at about the same time a toll was raised from iron produced in Scarsdale, Derbyshire, in forges which belonged to merchants.4 Small iron-producing districts such as the Forest of Chippenham also yielded a surplus which was sent to the market.5 Murage grants made to various towns such as Lewes, Oswestry, and York, empowering the inhabitants to raise tolls for the repair of the town walls, refer to iron brought to the towns in transit traffic or to be sold there.6 All this points to a considerable trade in home-produced iron.

For the making of arms and for building, both of which required large quantities of iron, English iron was used only to a limited extent. The evidence, supplied principally by the accounts of the royal works,

1 See below p. 159.
3 In 1301, a London ironmonger was sent to Southwark to meet merchants and smiths coming from the Weald with iron wares, L. F. Salzman, English Trade in the Middle Ages, p. 24. Oxford, 1931.
6 Straker, p. 33 (1266) — PRO, Patent Roll No. 103 (1284).
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shows that the home-produced iron delivered to the works mainly consisted of nails, horseshoes, wedges, spades, pickaxes, and the smaller types of bolt used as missiles for crossbows. Iron for large bolts to be thrown from siege-machines, and iron for those parts of the siege-machines which had to be particularly strong, was imported. Accounts listing the components of such machines in 1278-9 show this. A total of 15 tons 16½ cwt. of iron was used, of which not more than 2% was home-produced, this consisting of nails and wedges bought partly in the Weald and partly from a London ironmonger. All the rest of the iron had been imported from Normandy, Spain, and Sweden, as the accounts show. In all these countries iron manufactures were produced from ores of a high quality, so that they were superior to the majority of English products. Only the Forest of Dean iron was regarded as good enough for building in those days.

The import of iron from Normandy is on record from 1235 onwards; it was shipped from Pont-Audemer, an important port in the English king's French dominions. Norman iron was obtained from haematite ores bearing 47% of iron. The proportion of iron imported from Normandy, however, was not high, compared with that from other foreign sources; in the above-mentioned account of 1278-9 it constituted only a fraction of the total amount of iron used.

Much greater in volume was the import from Spain. In the account of 1278-9, e.g., Spanish iron amounted to about 65% of the total of iron used for the construction of siege-machines in the Tower. Since the west of France down to the Pyrenees belonged to the English Crown in the thirteenth century, attention was naturally drawn to the production area in the north of Spain, at Bilbao and its vicinity. An excellent iron was produced there from haematite and limonite ores rich in iron (from 48 to 58%). The earliest record of Spanish iron being imported is from 1254, at which date it was obtained from a Spanish merchant for use in the construction of siege-machines. Spanish iron is constantly referred to in medieval building accounts, especially in the south of England. Considerable quantities arrived in Spanish ships at the ports of Sandwich, Southampton, and Winchelsea between 1266 and 1308. In the west of England the main port was Bristol in the fourteenth and fifteenth centuries.

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1 PRO, Exchequer various accounts, Bundle 467, No. 7 (6 & 7). In 1275 (ibid., No. 7 (3)), 12 tons 8½ cwt. were imported from Spain for the same purpose, and only 7 cwt. (of wedges) from the Weald.

2 In 1253-54, e.g., 1,200 pieces of good quality (de bono ferro) were ordered for the King's works at Freemantle and Windsor from Gloucester, PRO, Liberatic Roll, No. 29.

3 PRO, Pipe Roll, No. 80 — In 1285 iron from the same source in Norwich. Salzman, Building, loc. cit., p. 288.


6 Ibid., p. 439 — E. M. Caena-Wilson, The Overseas Trade of Bristol in the later Middle Ages, pp. 171, 180 et seq. Bristol, 1937.
A third source of supply from abroad was Sweden, where high-quality iron was produced from ores superior to any ores mined in Britain. Swedish iron was imported by the merchants of the German Hanseatic League: import commenced in the thirteenth century and increased considerably in the fourteenth. The principal ports of arrival for Swedish iron were London and Hull, the latter supplying the north of the country. The iron obtained from Sweden was mainly the so-called Osmond iron which enjoyed the highest reputation and was greatly sought in the Middle Ages. \(^1\) Although Swedish iron was traded mainly under this name, Osmund iron was a particular sort produced from bog or lake ores. It was valued on account of its ductility combined with tenacity, which made it particularly suitable for wire-drawing.

However, comparatively little iron was imported into Britain before 1300. Foreign iron was required and used for special purposes where better quality and greater strength were needed. It was consumed in arms-making and building, and by certain crafts such as wire-drawing but for the purposes of agriculture and the needs of the village smith the native iron seems to have sufficed. At the markets where iron was bought for manors and estates in various parts of the country, imported iron was still rare in the thirteenth century. \(^2\) More gradually it came to be used after 1300, the period in which the home industry began to decline.

**THE CRISIS OF THE EARLY FOURTEENTH CENTURY AND ITS CAUSES**

The prosperity which had marked the economic life of the thirteenth century came to an end in the fourteenth. A slump in the production of minerals and metals set in which affected the whole of Europe. The depression in mining and industrial production was bound up with a decrease of general prosperity, and as the result of war and plague populations declined, after the rapid increase of the preceding two hundred years. \(^3\)

England remained comparatively peaceful, apart from the extreme north which suffered severely from repeated raids by the Scots. The enthusiasm aroused by the final defeat of the Scots in 1346 which liberated north England bears witness to what had been endured during the preceding fifty years. Iron working, however, had already been reduced before the Scottish invasions. \(^4\)

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1. Another name was 'Danzic iron' because it was imported into England via the city of Danzig (in Prussia, now in Poland) where English merchants had a trading station as early as in the fourteenth century, Beck, vol. II, p. 880.


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The decline in iron-working which commenced around 1300 was by no means confined to the north. It affected all the areas in which the production of iron was most intensive and of longest standing, for the greater the activity and the longer it had been carried on, the more wood had been consumed for charcoal burning. As a result, depletion of the wood resources began to cause anxiety for the first time in English history.

To the Cistercians, the cutting down of forests for their numerous forges was only a part of their general programme of reclaiming wastes and woodland for cultivation. After some twenty or thirty years the new abbeys were all surrounded with arable land and pastures. The same applies to their granges which were erected as centres of agriculture and husbandry in districts in which the land to be cultivated was too distant from the monastery for the monks to make the daily journey to and from work.¹

The success of Cistercians in forest clearing prompted secular landowners to follow their example and to increase their incomes by converting woodlands into fields and pastures. Farming became more lucrative with the growth of the towns which bought their produce. Thus forest clearing, which had been proceeding through the centuries, entered its crucial phase in the twelfth and thirteenth centuries in England, as well as in other European countries.²

In the area east and west of Leeds and in the Forest of Knaresborough the shortage of fuel brought iron-working almost to a standstill after 1300. In Knaresborough Forest, which had been the centre of an extensive iron industry throughout the preceding century, only two forges remained in 1304–5, of which one only was in operation. The other was reported to have been blown out, because the woods which supplied the fuel had been used up. Two years later the iron industry of the forest had shrunk to six small nail smithies.³ The industry in the parks of Rothwell and Roundhay near Leeds was as seriously affected. Iron had been worked extensively in 1320, but the consumption of wood became so great that in 1341 it was not possible to start iron-working there again. It was another fifteen years before a new ironworks was established.⁴ The depredations of iron-workers in search of fuel in the woodlands around Wakefield were the subject of complaints in court before the end of the thirteenth century. The local iron industry in the Forest of Skipton in Craven ceased work completely in 1307, because of smelting the ore was given as the reason for the low returns from an iron mine at Alston in 1292. In 1316, the decay of the hamlet of Whinfell was stated to have been caused by the destruction of an adjacent wood by iron forges, L. F. Salzman, English Industries of the Middle Ages, p. 26, note 4. Oxford, 1929 — Cal. of Inquisitions Miscellanea (Chancery), vol. ii, no. 257. London, 1916.

² CEH, vol. 1, p. 75.
the excessive consumption of wood by the two forges operating in the Forest.\(^1\)

The situation was even worse in regions where lead as well as iron was mined and worked, e.g., Derbyshire, which had a flourishing lead industry in the twelfth and thirteenth centuries. The demand for fuel by the two industries was much greater than the wood resources could stand, with the result that the iron industry in Duffield Frith began to decline rapidly at the beginning of the fourteenth century and soon ceased altogether.\(^2\) Another case of wholesale forest destruction occurred in the bishopric of Durham. Complaints lodged at the King’s Court in 1306, disclosed that large wastes had been created in the forests of the bishop. Natural causes such as windfalls were held partly responsible, but also neglect to preserve the timber (mauvaise garde) and, last but not least, extensive charcoal-burning for the smelting of iron and of lead. The bishop was sternly admonished to prevent further destruction.\(^3\)

The woodland resources which supplied the iron industry of the Forest of Dean with fuel were better cared for. Although great inroads were made upon them from time to time\(^4\) they were not devastated, thanks to effective supervision by alert authorities. Moreover there was plenty of wood for charcoal in the neighbourhood outside the Forest bounds. Of the twenty-seven forges operated in 1255 and earlier, twenty-three obtained their charcoal partly or entirely from outside the Forest. (The charcoal from outside came mainly from Monmouthshire, which in those days was a part of Wales.) Nevertheless the destruction and waste of woods continued, as is shown by a survey of the forest and adjacent districts made in 1270. It was observed by the surveyors that ‘much evil’ (multa mala) had been done to the Forest by the forges, the number of which amounted to 43 at about this date. Destruction had extended also beyond the Forest area. In the woods belonging to the Bishop of Hereford and situated between Ross on Wye and the northern fringe of the Forest of Dean, nine thousand oak trees had been felled. The damage done by charcoal burners was so great, that in the same year charcoal burning in the area was totally prohibited. The order, however, had no lasting effect, so that twelve years later in four of the demesne woods of the Forest charcoal was being

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\(^1\) *VCH, Yorkshire*, vol. ii, p. 350 — *EYCH*, vol. vii, p. 27.
\(^3\) *Routuli Parliamentorum*, vol. i, p. 198. Gille (p. 5) misreads the text as stating that the English were not willing any longer to produce iron and steel but preferred to import it from their possessions in France.
\(^4\) M. L. Bazeley, ‘The Forest of Dean in its Relations with the Crown during the Twelfth and Thirteenth Centuries’, *Tr. of the Bristol and Gloucestershire Archaeological Society*, vol. xxxiv, pp. 296, 266, Bristol, 1910 — The position of the forges which are enumerated in the Forest Proceedings of about 1250 and of 1270 (PRO, Eschequer KR, Bundle 1, No. 25, and *Treasury of the Receipt*, No. 28), is shown on Map IV.
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burnt in nearly nine hundred pits. On the whole, the restrictive measures taken to protect the timber of this region, although they frequently fell into oblivion after a few years, did prevent devastation as great as that which was occurring in other parts of the country.

Remote districts and those in which the industry was still in its infancy remained, of course, unaffected by the shortage of wood. In the Forest of Pickering in the North Riding of Yorkshire, for example, the number of works had increased by 1313 and was still increasing after this date.

Use of mineral coal

The effect of the wood shortage upon the iron industry would have been worse had it not been for the mining of mineral coal which relieved the situation to some extent. Exploitation of mineral coal, which apparently had ceased with the departure of the Romans, began again at the close of the twelfth century. In about the year 1200 mineral coal was recorded at Bruges among exports from England to Flanders. By 1240 it was certainly being mined around Pontefract in Yorkshire, and in 1257 it was used by the smiths of Nottingham so extensively that Queen Eleanor who visited the town, was soon forced to leave again because of the unendurable smoke from the mineral coal. The use of mineral coal however was still mainly confined to the forges of blacksmiths and nailors and even there it was not general.

New steps for woodland preservation

In the thirteenth century when the destruction of woods was greatest, new steps were taken for the preservation and protection of the nation's timber resources. The system of 'coppicing', which secured the replacement of felled trees by natural growth, is first referred to in a Royal order to the Constable of St. Briavels in the Royal Forest of Dean, issued in 1237. He was admonished to take care that the underwood should be cut in such a way that it could grow again (revenire) and that no damage should be done to the 'coppice' (coepicia) in the Forest of St. Briavels. Stretches of wood which had been cut down were to be well enclosed, so that neither wild animals nor cattle could enter.

Regulations for protecting young growing trees against grazing cattle were by no means confined to the Royal Forest of Dean. In 1294, e.g., when the wood and underwood growing at Sutton in the Forest of Galtres in the North Riding of Yorkshire, was sold to St. Mary's

1 PRO, Forest Proceeding, Exchequer KR, Bundle 1, No. 25, and Exchequer Treasury of the Receipt, No. 29.
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Abbey at York, the stipulation was made that in districts in which small trees were cut for the making of faggots no cattle should be admitted for one year—a comparatively short period. In the Forest of Wensleydale the woods granted to the abbey of Jervaux by the Earl of Richmond in 1281 had to be enclosed for a period of five years after cutting.¹

The decline of the iron industry which commenced about 1300, preceded the catastrophe of the 'Black Death': bubonic plague, which swept over Europe in successive waves and reached the English shores in 1348. Compared with the great expansion of the industry and the intensification of work and production between 1200 and 1300, the decline after the latter date is marked. In general, however, it was a slowing down of the industry which only in certain districts resulted in its complete extinction. It was, in effect, a slump, following a boom unprecedented in any of the earlier periods in the history of the British iron industry, and the phase was paralleled in the other iron-producing countries of Europe.

It is notable that in a period of marked regression one branch of the English iron industry not only remained unaffected, but actually expanded. This was the manufacture of steel.

¹ York Minster Library, Register of St. Mary’s Abbey, fol. 136v — Cal. of Charter Rolls, vol. iii, p. 96 (monachi faciant claudere portionem cissam durante clausura per quinquennium).
CHAPTER VII

STEEL IN MEDIEVAL ENGLAND

Very little is known about the production of steel in medieval England. The one outstanding fact is that steel was imported in considerable quantities mainly by merchants of the German Hanseatic League, whose London office was the Steelyard at the site now occupied by Cannon Street Station. The bulk of the imported steel came from German Westphalia including the district of Siegen which was one of the oldest centres of steelmaking in Germany.\(^1\)

Steel was also obtained from France as early as in the thirteenth century: in the years 1235–36, and again from 1278–79 steel was sent over from the port of St. Omer, south-west of Le Havre in Normandy. It was to be employed for making parts of carts, and, in the second case, also for tools to be used by masons working at the Tower of London and at Westminster.\(^2\)

The demand for steel seems to have been growing in England in the thirteenth century. An extensive use of steel for making cart-clouts is indicated by accounts from the year 1257 referring to Royal Manors in Bedfordshire, Monmouthshire, and Warwickshire.\(^3\) Steel was in demand for agriculture throughout the country. It was employed to tip ploughshares and plough-shoes, and also to strengthen parts of horseshoes.\(^4\) Steel, in addition to iron, was also used for the machinery of mills, e.g.,

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2 PRO, *Pipe Roll*, No. 80, Exchequer various Accounts, Bundle 467, No. 7 — See also Gille, p. 5.

3 PRO, *Ministers' Accounts*, General Series, Bundle 1094, No. 11.

4 Rogers, vol. 1, p. 473.
Steel in Medieval England

in the Manor of Tanton in Surrey, in 1241.¹ Craftsmen in towns and villages needed steel implements with sharp edges and points, such as chisels, choppers and pick-axes; and edges of hard steel were welded on to the iron body of the implements. This method is described in an account of the work of bloomsmiths at Tudeley, in Kent, in 1352.² Steel was used by girdlers: in a document of 1327 it is mentioned as one of the materials used to adorn girdles or belts of silk, wool, leather, and linen.³

In addition to agriculture and smithcraft, steel was in demand for arms-making; according to the evidence available, it came into more general use for such purposes in the course of the thirteenth century. Engines of war such as catapults required steel to strengthen parts upon which special pressure was exerted. In 1249, when the Royal Castle of Dissard in County Flintshire, in Wales, was fortified and equipped with war material, four horse-loads of steel were bought for the purpose.⁴ For armour and weapons also steel came more and more into use. In the same century, the wide-brimmed steel hat appeared, which after 1300 was largely superseded by a lighter helm, the bascinet.⁵ In a Royal order of 1324 'steel bacinet's' are referred to with which a certain number of men in the various counties should be equipped. In the same order, and also in another issued in 1322, 'gauntlets of steel' are mentioned.⁶

The application of steel to missiles first occurred in the reign of Henry III (1216–1272). In 1227 a Royal order was issued to the Sheriff of Hereford to buy iron, steel, wood, charcoal, and feathers to make quarrels in the castle of Hereford.⁷ The quarrels were to be 'winged' with feathers and their heads pointed with steel.

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² 'In securi fabrice superponenda cum ascere pro ferro scindendo.' Arch., vol. LXXV, p. 160 — Fabric Rolls of York Minster 1416 and 1419; steel bought 'pro acquacione securium cementarium' (i.e. masons), Surtees, vol. XXXV, pp. 34, 35, 38.
⁷ By the later years of Edward III who reigned from 1327 to 1377, breast and back plates of steel had come into use, Ch. Oman, A History of the Art of War in the Middle Ages, vol. II, p. 377, second edition, London, 1924.

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The manufacture of missiles increased considerably during the Hundred Years War with France (1337-1453). The Hundred Years War had a disastrous effect upon the French iron industry causing a depression which lasted almost to the middle of the following century, but in England which was spared the ravages of war, it had exactly the opposite effect. Weapons were required not only for the military expeditions to France, but also to arm the population in England. An order referring to this was issued by Edward III in 1345, so that the country should be guarded against a threatened invasion by French and Scottish armies. All men holding a lay fee from the Crown were assessed to arms, to enable the king to have an armed force in readiness for the defence of the realm.  

The increase in the production of arms is most significant in respect of steel. In the course of his preparations for an invasion of France through Brittany, Edward on 18th April 1341 issued an order to the Sheriffs of the various English counties to supply bows, arrows, and arrowheads. Arrows, the heads of which were of iron pointed with steel, were subsequently delivered only from the counties of Gloucestershire, Shropshire, Staffordshire, and Yorkshire. Other counties, Sussex included, supplied bows and arrows without any ironwork or steel. This is significant, as it indicates the centres of steelmaking in those days: Gloucestershire (with the Forest of Dean), the Midlands, and Yorkshire.

Yorkshire supplied 500 bows, and 580 garbs of arrows, 360 of which had iron heads pointed with steel (cum capitibus ferreis aceratis). Apparently they were of local manufacture, as it is clearly stated that they were bought and collected at various towns within the county. They were taken in waggons to the Royal Castle in York, and subsequently shipped down the River Ouse to Linn, and thence probably to London. In the towns of Shrewsbury and Stafford 576 garbs of arrows, all with steel-pointed heads, were bought at twelve pence per garb. They were sent in two waggons to the Tower of London. The largest amount came from Gloucester and the Forest of Dean, the ancient arsenal of military equipment of the English kings in their various wars. The Sheriff of Gloucestershire provided 837 garbs of arrows well pointed with steel (sufficienter et bene asseratae). In addition, he supplied 750 steel-pointed arrowheads, the hundred at 2/6d. For their transport to the Tower of London three waggons were hired, two at Gloucester and one in the Forest of Dean.

It seems strange that the smiths in the Weald of Kent and Sussex did not contribute to these deliveries. About eighteen years later, however, and some months before he left England for the wars in

1 Gille, pp. viii and 6.
3 PRO, Pipe Roll, No. 165.
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France, Edward III appointed by order of the 24th March 1359 his ‘flecher’, i.e. arrowmaker, Thomas atte Legh, to engage in the counties of Kent and Sussex as many smiths as were required for the forging of 500 arrowheads of steel (factura quingentorum capitum sagittarum de ascerere). On the 30th October 1359 an order was issued to get iron, steel, and charcoal for the king’s works in the Tower and to engage for the working of these materials smiths and other workers wherever they could be secured. A fortnight later this was followed by another order to buy 1000 garbs of arrows with heads hard and well steeled, for the archers of the king’s bodyguard.

As the war proceeded, the demand for missiles which by no means diminished, gave unscrupulous arrowsmiths the opportunity to produce defective heads. To protect and maintain the quality a Statute was passed in 1406, decreeing that every head of an arrow or quarrel was to be hardened at the point with steel and engraved with the mark of the manufacturer.

Despite the small quantity of steel required for the making of arrowheads or pointing them, there is no doubt that the steel was made in various industrial regions in the Hundred Years War. In the above-mentioned reports on deliveries of steeled arrowheads, reference is made to the collection of the goods in the principal towns of the counties, which indicates that they were brought in from their various places of manufacture. In addition to the Royal purchases, there was a widespread demand by the nobility for steel for their castles and farms, and also for tools for craftsmen in the towns of the realm. Considering all these facts, it seems unlikely that all this steel was imported especially as the quantity used greatly increased in the course of time. So that apart from the importation of steel from abroad, of which ample evidence is available, there seems no doubt that a considerable amount was produced in the country in the Late Middle Ages.

**Methods.** Steel would have been produced in medieval England as raw steel from manganese-bearing ores or by cementation. Steel bought by the ‘cake’ at Cuxham in 1300, and nine times between 1331 and 1345 at Oxford was raw steel. The cakes, or ingots, were evidently produced in England. Imported steel came to England from abroad after it had been forged, but not in the raw state, for otherwise the foreign steel-maker would forgo the profit he gained from forging. It is difficult to assess the weight of a cake of raw steel. It can only be done by comparing the purchase prices of raw and of forged steel. Forged

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4 Rogers, vol. i, p. 473. In Germany the term 'Stahlkuchen' which corresponds to the English term 'cake of steel', was applied to raw steel, e.g. in the ancient steel manufacture of Siegen in Westphalia, H. Schubert, loc. cit., passim.

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steel was sold in garbs at an average price of 94d. per garb between 1261 and 1350. In the same period, the cake of raw steel was sold at 10½d., which implies that it weighed more, since the product in the raw state would not be priced higher than in the finished state. The garb of forged steel had a weight of a hundred (centena) in 1341, which was 27 lb.1 Allowing for the loss in forging, the weight of a cake of raw steel would be approximately 36 lb.

There is also evidence of wrought iron being converted into steel in fourteenth-century England. An entry of 1368 in the account rolls of the Abbey of Durham referred to $4\frac{1}{2}$ stones (i.e. 63 lb.) of iron which was converted into steel (in operatione IIIA petrarum et dimidie in calibem). The steel served for making cutting wedges and points which were to be welded on to iron implements for masons and stone breakers such as axes, puncheons, chisels, and wedges.2 The process employed was probably cementation or surface-carburisation, which was effected by heating wrought iron with carbonaceous matter. The method was known and practised in Roman Britain, and improved in the late Saxon period apparently through the influence of the Scandinavian invaders. It is described by Theophilus, also called Rugerus, a priest and monk of the twelfth century, who probably lived in the German Rhineland.3 The degree to which the surface of the iron was converted into steel by carburisation depended upon the duration of the treatment. At the end of the process the carburised iron, still glowing, was taken out of the fire and quenched in water to harden it.

A steely iron could also be produced directly from the ore. For this purpose the majority of the clay ironstones of the coal measure in Yorkshire, Shropshire, and Staffordshire were suitable because of their content of manganese: just as suitable, if not more so, than some of the brown haematites mined in the Forest of Dean.4

For steeling, i.e. the welding of steel on to missiles and cutting tools, English iron was 'excisibly well adapted', as a Yorkshire ironmaster put it.5

The skill of the English craftsman in handling steel and his method of working it is shown in the helms manufactured in the second half of

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1 PRO, Pipe Roll, No. 186 (garb = centena, or a hundred). The figure of 27 lb. is arrived at by comparing with the weight of Osmond iron which was similar to steel in 'form and price' (Rogers, vol. 1, p. 473); it also was sold by the garb or hundred which was an ancient weight of 27 lb. in the Westphalian manufacture of Osmond iron, F. A. A. Eversmann, Die Eisen- und Stahlerezeugung auf Wasserwerken zwischen Lahn und Lippe, p. 281. Dortmund, 1804.
2 Surtees, vol. 6, p. 571.
5 'Being very spongy and porous, it will with less degree of heat open its pores large enough to receive the particles, and intermix or weave its surface with the surface of the steel laid to it,' Remarks on the Nature and Quality of Iron, by Britannicus (a pseudonym for John Cockshutt senior of Wortley, Comp. Lewis, vol. iv, p. 1849), The London Magazine, vol. xxxi, p. 68. London, 1752.
the fourteenth century. The steel helm of the Black Prince, until recently suspended above his tomb in Canterbury Cathedral ever since his death in 1376, is very well known, but it is not certain whether it was made in England. Workmanship equally admirable is seen in the helm of Sir Richard Pembridge (Pl. XII) who died one year later and whose alabaster altar-tomb is in Hereford Cathedral, and there is no doubt that this helm is of English make.

The fine quality of the steel is said to be such that no penknife would scratch the polished surface. The helm is formed of three pieces: the cone, the cylinder, and the top-piece. All three are welded so well that no seam is visible. The metal is thickened and turned outwards round the eye-piece as a protection. The bottom edge is rolled inwards over a thick wire to prevent the surcoat worn by the knight being cut by the edge of the bottom piece. Long hand-hammering of the surface is believed to account for the helm's resistance to deep corrosion.1

The high standard of work in steel was maintained in the following century. In the year 1464 a test was arranged in London between an English and a foreign artificer. Each was to produce four steel punchoons or dies which were to be made by a compatriot. Two of the dies were to be engraved and two embossed, the designs to be a naked man and a cat's head. The trial was decided by the jury in favour of the English smith whose products were regarded as being 'better kunynger (i.e. more skilfully) wrought'.2

The demand for war material stimulated production, in particular during the Hundred Years War with France, and in this way it aided the English iron industry in a time of depression. Simultaneously the increased demand for armament extended to steel. As a result, the manufacture was intensified and—for the first time in English history—conducted on organised lines and sponsored by the State to meet the requirements for war and civil defence. The supply of home-made steel, however, was small, and had to be supplemented by importation from abroad. In an English poem of 1436 which exalts the political and commercial advantages afforded by command of the sea, the metals imported into England are enumerated. They were, Osmond iron and copper from Sweden, shipped to England by the merchants of the German Hanseatic League, iron from Spain, and steel from Germany.3

CHAPTER VIII

THE MEDIEVAL BLOOMERY

The increased demand for iron in the twelfth and thirteenth centuries caused a considerable increase in production which is reflected in the greater number of ironworks (Map III). Steel too was more in demand, in particular during the wars of the fourteenth century, at the beginning of which the iron industry had entered a phase of depression owing to the depletion of wood resources. The depression was at its lowest level when the Black Death reached England in 1348. By the appalling mortality it caused, the plague became one of the greatest catastrophes in the economic and social history of England. Its far-reaching results made it a landmark in the history of every branch of industrial activity including iron-making.

IMPROVEMENTS IN FUEL SUPPLY AND MINING

As has already been noted, the extensive forest clearing of the thirteenth century resulted in a shortage of wood for charcoal. It was however not only the diminishing quantity of wood resources which increasingly handicapped the iron industry, but also the type of wood available for charcoal burning. In the clearing of woodland for sheep-farming and agriculture great trees were felled and delivered to the charcoal burners, and in the remaining woods dead wood and wind-fallen trees were mainly used in complete disregard of the rules known in Antiquity and laid down by Theophrastus who had emphatically recommended the wood of young trees to obtain charcoal of good quality. Dead wood consisted of dried-out branches of trees which were either lying on the ground and bound to decay, or still hanging on the trees, and its use was widespread. In 1195, the Cistercians of Fountains Abbey in Yorkshire obtained a licence to burn charcoal from dead wood in the Forest of Knaresborough. The sale of dead wood was a well-paying proposition. In an assessment of 1341 whereas the profit from ore for

1 App. II.
smelting was estimated at 1s. per week, the profit from dead wood for fuel was expected to be twenty times as high.\(^1\)

A favourable development was the growing practice of using brushwood or underwood, which in the thirteenth century was employed for charcoal burning only as an addition to dead wood and stems and roots of trees felled in the clearing of woodlands.\(^2\) In the fourteenth century, particularly after the Black Death of 1348, a change apparently took place, inasmuch as preference was given to young and small trees. In 1377, for example, the ironmaster William Fitz Elias of Bramley obtained permission to take all underwood and all the small oaks growing in a wood near Calverley and Pudsey, west of Leeds, for smelting. Large trees were to remain untouched, except loppings from branches to be used as firewood for preparing the meals of the workers.\(^3\)

Recourse to the use of wood from young trees is also reflected in the planting of protected coppices which began in the Forest of Dean in 1237,\(^4\) but there is no evidence of it elsewhere before 1400. After about this date, however, coppices were planted even in remote parts where iron-production was on a small scale and there was no lack of wood resources, e.g. near Barnard Castle, County Durham, in 1437.\(^5\)

Nothing definite is known about the length of time the trees were allowed to grow before felling. A statement made very much later, however, suggests that some of the ‘old Clergy Spring-woods’, i.e. the coppice woods of ecclesiastic landowners before the Dissolution of the Monasteries, were allowed to grow until they were 25 or 30 years old.\(^6\)

The art of mining, still in its early phase, appears to have improved in the thirteenth century, which is signified by the employment of miners in the wars of the age. There is hardly a siege in which it does not occur.\(^7\) The miners of the Forest of Dean seem to have been experts and from 1222 onwards there is evidence that they were recruited for the royal armies. They served in the campaigns against the Scots, and also overseas, e.g. in Gascony in 1253.\(^8\) Their main task was to undermine fortifications, which shows that they were experienced in the art of tunnelling. Quarrying with trenches, as well as tunnelling were used in the Forest of Dean (Pl. XIII and XIV), where some of the trenches cut into the rocks were as deep as 40 feet and more.

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\(^1\) PRO, _Treasury of the Receipt, Miscellanea Books_, vol. 176, p. 29.

\(^2\) In 1229, itinerant forges in the Forest of Dean were allowed wood ‘de subbosco, mortuo bosco, et veteribus roboribus que folia non ferunt’, _Close Rolls of the reign of Henry II, A.D. 1227–1231_, p. 260. London, 1902.

\(^3\) BM, Add. Charter No. 16834.

\(^4\) See above, p. 114.


\(^7\) Ch. Oman, _A History of the Art of War in the Middle Ages_, vol. ii, p. 50, second edition. London, 1924.

\(^8\) Hart, pp. 91 et seq.
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Exactly as in the Roman period the rocks were broken with short iron pick-hammers.¹ This is indicated in an order given to the Sheriff of Hereford in 1245, to send to Chester twelve miners of the Forest of Dean, well skilled in their art, with four iron hammers for breaking rock and six crows for raising it.²

Six miners' picks are carved on the font in Abenham Church, Gloucestershire (about 1450). Beneath the picks two shovels are represented.³ The shovels, used for gathering the ore and putting it into baskets or tubs, were made of oak.

Another method probably going back to the Middle Ages was to extract the ore from deeper deposits by bell-pits, of which traces have been found in many parts of the country such as Sussex, Lancashire, Yorkshire. A bell-pit was a small shallow pit, about 5 feet in diameter at the top and gradually widening to about 12 feet at the bottom, resembling in shape a bell or bee-hive. The pits were generally from 15 to 20 feet deep. The width at the bottom was limited, since there was a danger that the soil covering a cavity widened at the bottom would fall in. Accidents caused by this did happen. In 1357, e.g., a miner working such a pit at Handsworth, in Yorkshire, was crushed to death by a fall of rock.⁴ The ore in pits of such small dimensions was soon extracted, after which the pit was abandoned, and a new one was driven mostly in the immediate vicinity.

The method of bringing the ore to the surface was quite simple. If trenches sufficed, the ore was simply shovelled up; in deeper mines it was collected in shallow boxes or trays. These were slung over the shoulder and kept in position by a stick. The smaller boxes were carried up by boys, the bigger ones by men.⁵

That hard ore was washed at the pit-head is frequently mentioned in mining rights granted in the peninsula of Furness before 1235 (red haematite).⁶ After the ore had been taken to the bloomery it was roasted or burnt, of which evidence is supplied by the accounts of Tudeley in Kent and Byrkeknott in Weardale. At Tudeley a proper roasting oven (furnus) was used for 'elyng' (derived from the Saxon 'aelan' which means burning),⁷ which reduced the ore in weight but not in bulk. To obtain a proper size suitable for smelting, the ore was crushed with a hammer, as is shown in the accounts of both the above-mentioned bloomeries. At Byrkeknott the wife of the bloomer frequently helped with the ore-crushing. The small particles of the broken ore were afterwards separated from the larger pieces by sieving.

¹ See above Fig. 11 in chapter 2.
² 'in arte sua peritores', PRO, Liberate Roll, 29 Henry III, membr. 4 — Hart, p. 22.
³ Hart, p. 25, illustration facing p. 42.
⁵ Fell, p. 75 — Hart, p. 31 — Straker, pp. 103, 106.
⁶ Fell, pp. 14 et seq., 416 et seq.
ITINERANT AND PERMANENT BLOOMERIES

Archeological data about ironworks in medieval Britain are sparse compared with those from the time of the Roman occupation. In order to reconstruct the layout of a medieval bloomery and the process of working it items from documents such as grants, leases, and accounts have mainly to be relied upon. Fortunately detailed descriptions of two bloomeries have been preserved. One was at Tudeley east of Tonbridge, in Kent (Map I, No. 31), the accounts of which extend over two periods, from 1329 to 1334 and from 1350 to 1354. The other is an account of a newly erected bloomery at Byrkeknott near Bedburn in Weardale, County Durham. It is a detailed account of the operations conducted in one year (from November 1408 to 1409).

The medieval bloomeries, in documents mostly called forges (forgesiae, or fabricae), were of two different types: itinerant, and permanent.

Itinerant forges were very small so that they could easily be moved to a different locality. In 1281 they were described as small sheds without nail, bolt or wall. Apparently they were of wood and similar in dimensions to sheds erected in forests for charcoal burners, and herdsmen. In 1234 such sheds in Glaisdale, Cleveland, were 20 feet long and 12 feet wide.

Permanent forges were much larger, the term "great forge" being occasionally applied to them. A permanent bloomery consisted of a forge house, buildings which served as workers' domiciles or as stables for the pack horses which carried ore and charcoal to the bloomery, with a yard between the buildings.

Sometimes the whole plant was surrounded by a wall and perhaps also a ditch.

1 Published by M. S. Guiseppi, Arch., vol. lxiv, pp. 145-164. See also Straker, pp. 34-36.
3 "monachi posunt facere duas parvas logias ad ferrum suum comburendum sine clavo cavilla pariete et muro", grant of wood in the Forest of Wensleydale, Yorkshire, by John Earl of Richmond to Yervaux Abbey for the smelting of iron, Cal. of Charter Rolls, vol. iii, pp. 95-96.
4 Surtees, vol. lxxxvi, p. 112.
6 Bloomery erected by the Augustinian Priory of Conished, Furness, between 1220 and 1246 by the side of one of the tributary streams of the river Crake; one acre granted 'ad unam forgeam cum uno atrio et ad alias domos ad hoc necessarias ibidem edificandas', PRO, Patent Roll 12 Edward II, membrane 22. Abstract Fell, pp. 161-162 — At Byrkeknott the number of houses built in 1408 was four, EHR, vol. xiv, p. 518.
7 E.g. at the forge the Cistercians of Fountains had at Bradley near Huddersfield 'sex acres propinquiores closure forge sui ante portam', BM Tiberius, c. xii, fol. 200 (undated, but before 1219, cf. ibid., fol. 202).
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The forge house itself was of wood. In 1343 only carpenters were employed to rebuild the Tudeley works in Kent, roof and walls of which were constructed of wooden boards nailed to vertical posts. Such buildings did not last long. The forge house at Tudeley had to be rebuilt again after only seven years.

A certain amount of land outside the actual plant was generally granted for various purposes, such as dumping of refuse (slag), and for the grazing of the pack-horses and domestic animals which the workers needed for their maintenance.

BLOOMHEARTH AMD STRINGHEARTH

Ironworks with not more than one furnace, in the Middle Ages generally termed a hearth (astrium, focus), in which the process of iron-making was conducted throughout by the same workers exactly as in earlier centuries are still referred to in medieval documents. The commonest type, however, had two separate hearths, making possible the division of labour. There is ample evidence for this, commencing with the earliest medieval documents which have been preserved. In 1161, for instance, the Cistercians of Kirkstead in Lincolnshire were granted land for the erection of four forges or fires in the district of Kimberworth, north-east of Sheffield. Two of the forges took iron ore for smelting while the two others were used for working up the smelted iron. The document shows that iron was made at this early date at two separate working places or hearths which in later documents are distinguished as 'bloomhearth' and 'stringhearth'. Sometimes the two types were built at quite different localities as is shown in a grant made to the Cistercian Abbey of Louth Park, Lincolnshire, at the close of the thirteenth century, and confirmed in 1314. One of the two forges granted to the Abbey was in the woods of Barlow, near Chesterfield, Derbyshire, and was referred to as a bloomsmithy (fabrica blomeria). The other, at the Abbey’s grange (curtis) situated at Barlow, was a forge for working up the iron (fabrica operaria). Each was equipped with one

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1 Arch., vol. lxxiv, p. 148. In a lease of 1354 the building is referred to as 'domus fabricae’, ibid., p. 150—At Byrkeknott the forge house built in 1408 also was made of timber; it was roofed over with turf, EHR, vol. xiv, p. 310.
2 For the forge of Conished Priory, Lancs. (see note 6, p. 125), 1 acre was granted—In 1428 an ironmaster in Weardale, County Durham, was granted an enclosed place sufficient for grazing of six horses, PRO, Durham Cartulor 37, membr. 30—The custom continued; at a bloomsmithy near Sheffield, blommer, smith and horsedriver each had 'a cow kept both wintyr and sommer'. G. I. H. Lloyd, The Cutley Trades, p. 433 (A.D. 1574). London, 1913.
3 Fell, pp. 18, 162, 430.
4 'III forias faciendas, duas silicet ad quoqueum ferrum et duas ad fabricandum', VCH, York, vol. ii, pp. 343, 388—Dead wood 'quantum sufficit illi qua tuor ignibus', BM, Yespasian E 18, fol. 128c.

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hearth. If the bloomsmithy in the woods of Barlow was not being worked (quando non operatur in fabrica que est in bosco), the monks were allowed to have iron made in two hearths at the grange. The system of making iron in two separate hearths even extended to small itinerant bloomeries. At Dacre, in Nidderdale, Yorkshire, Fountains Abbey had a permanent forge near the grange and in the woods a movable forge with sheds and two hearths.1

Remains of medieval bloomeries are not rare in Britain, but most of them when excavated were too much damaged for their design to be ascertained. There are, however, exceptions, such as the two shown in the illustrations, both found in north Lancashire.

The two hearths are very similar in construction and dimensions. The shape of the smelting pit, similar to another which was discovered at a contemporary site near Coniston Lake, distinctly shows its descent from the ancient bowl furnace.2 It is, however, larger, which is particularly significant at Springs bloomery.

Hearths without pits were discovered in the same region, but the great width at the bottom precludes the possibility that they were used for iron-smelting. They may have served for roasting the ore or for working up the bloom and forging.3 In the Wealden area a similar hearth, also ascribed to the fourteenth century, was found at Thundersfield in the parish of Horley, Surrey. It was a circular floor 9 feet in diameter, not of sandstone slabs as in Lancashire but of clay which had been burnt red and hard to a depth of 6 inches. Whether it served for smelting can hardly be determined, since no proper pit for collecting the iron and liquefied slag was discovered. The only indication which might suggest this use is the presence of two semicircles of stone in the centre.4

The large circular platform surrounding the pit (as shown in Fig. 15) served as a working platform for the smelters, and on it the charcoal and ore were kept ready for charging, which accounts for the large dimensions. At Springs bloomery (Fig. 16) the platform seems to have been elevated above the ground by about one foot.

There is no doubt that the size of the pit or bowl gradually increased when larger blooms began to be produced. Blooms of 195 lb. produced

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2 Remnants of a shallow bowl-shaped pit in which iron-smelting had been carried out probably in the thirteenth century, were discovered at Downpatrick, Co. Down, Ulster. B. Proudfoot, 'Excavations at the Cathedral Hill, Downpatrick', Ulster Journal of Archaeology, vol. 17, pp. 98-99. Belfast, 1955.

3 Arch., vol. lV, p. 90 — Fell, p. 171.

Fig. 15. Fourteenth-century smelting hearth. Plan of hearth at Throng Moss, Torver Low Common, Lancashire.
From Fell, p. 168.

(A) small charcoal found here; (B) pit for smelting 1 foot 6 inches in diameter with bottom of burnt clay; (C) the stones forming the flat part of the hearth or platform bear no signs of heating, 64 feet in diameter and rudely constructed; (D) possibly tuyere hole; (E) slag hole.

Fig. 16. Cross-section of smelting hearth at Springs Bloomery, Lancashire, before 1400, depth of pit 2 feet 5 inches.

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at Byrkeknott in 1408–09 would certainly have required a larger hearth, but there is no reliable archaeological evidence.\(^1\)

An intermediate stage in the evolution of the furnace from the bloomery to the blast-furnace is represented by the so-called ‘Stückofen’ or high bloomery furnace which may be regarded as the final development of the furnaces producing malleable iron directly from the ore.\(^2\) The Stückofen is distinguished from the smelting furnaces of the bloomsmithies mainly by its greater height (10–16 feet). Although it was in operation in Central Europe, particularly in the Alps, in Germany, Eastern France, and in Hungary, from the fifteenth to the nineteenth century, there is no evidence that such furnaces were ever used in Britain. The chimney at Byrkeknott forge, built by the bloomer over the bloomhearth in 1408, does not suggest anything of the sort.\(^3\) A chimney for increasing the draught appears to have been in common use by the early fourteenth century in the forge of the English blacksmith.\(^4\)

**THE PROCESS**

In the Middle Ages the smelting process was essentially the same as in the prehistoric and Roman eras, but more detailed evidence of working methods and appliances employed is available.\(^5\)

An essential part of the process conducted in the smelting or bloom hearth was the working with iron bars. The first evidence in England is in the accounts of Tudeley forge in Sussex given in the years 1350 to 1354. The bars were termed ‘andiron’, or ‘angisen’ at Tudeley, and ‘naundiron’ at Byrkeknott in Weardale, in 1408. The use of such bars

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1 Scanty remains of a circular furnace with a diameter of 4 feet at the height of 24 feet and of 4 feet 9 inches at 3 feet from the bottom level were discovered in 1914 on lands close to the river Mawddach near Gell-germlyn in the parish of Llanfachreth, Merionethshire, supposed to be one of the forges of Cymmer Abbey mentioned in records from 1377–1425, at the PRO. An Inventory of the Ancient Monuments in Wales and Monmouthshire, VI, County of Merioneth, pp. 96 and 106, London, 1921. The forges referred to, however, were 7 and 8½ miles distant from the site of the furnace, at which no traces of a clay lining to which ‘molten iron still clings’ ([loc. cit.], p. 106) were found, when the author inspected the site in 1931. Nearby the opening of a copper mine is still visible.

2 A large bowl-shaped pit with enclosing walls and a diameter of 6 feet at the top, from which it gradually curved inwards down to a diameter of 4½ feet, was found at Lindale Church, near Grange, Lanes., but no date is available except that it antedates the first building of the church in the early part of the seventeenth century, J. W. Jackson, ‘On the Discovery of a Bloomery at Lindale Church’, *Tr. of the Cumberland and Westmorland Antiquarian and Archaeological Society*, N.S., vol. xiv, pp. 256–261 (illustration on p. 258). Kendal, 1914.


5 See below Plate XIV. In a manuscript of the early fourteenth century, written in Italy, but illuminated in England, a hearth with a chimney is shown in a scene representing St. Dunstan’s encounter with the devil. BM, Royal MS. 10 E IV, fol. 250r.

6 For the various implements used see App. VII. According to evidence they remained the same from the fourteenth to the sixteenth century, which shows the great constancy of the process — Prehistoric process see Chapter II.
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was fairly general in medieval ironworks which is proved by evidence from the Bernese Jura, the Catalan forges in the south of France and the north of Spain, and from the iron-producing area of the Siegerland in German Westphalia. The bar served various purposes. By frequent stirring a closer contact of ore and incandescent charcoal was achieved. Particles of iron remaining scattered in the charcoal were made to unite with the bloom into which the metallic parts conglomerated at the bottom. Slag which tended to agglomerate in the region of the tuyere, since it consolidated more quickly there on account of the cold blast air, was detached with the bar. By this action the blast hole was kept clear and the slag was pushed back into the hearth where it deposited its iron content. At the end of the smelting process the bloom was raised, so as to facilitate its extraction.

In the course of the smelting process water was used to prevent unnecessary consumption of fuel. The covering of the fire, consisting of small charcoal firmly pounded, was renewed with moistened charcoal after every addition to the charge. From time to time water was sprinkled on to prevent flames escaping through the sides of the covering, since otherwise the fuel would burn away too quickly. Water was required also for sprinkling the bloom after it had been extracted with tongs, so as to facilitate the removing of slag from the surface by beating with a sledge hammer. The water was carried to the bloom-hearth in clay pots or in wooden buckets (App. VII).

A technological advance is implied in the addition of slag (cinder) from ancient ironworks. In England the practice was known around 1400. At Byrkeknott in Weardale twelve wain loads of slag were obtained in 1407 from a prehistoric camp situated at Hoppyland, north of Bedburn. For a bloomsmithy in the woods south of the River Tyne and west of Crawcrook permission to collect slags from Ambrosegarth was given by the Bishop of Durham in 1428.

The beneficial effect of the slag bath upon the iron was well known to the smelters, as is shown in the accounts of Byrkeknott. Slag was added for the purpose of 'tempering' the iron during the process of smelting (pro temperatione ferri ibidem de novo faciendi). The slag from ancient bloomeries was basic, containing about half the iron of the ore as ferrous silicate and oxide. Basic slag eliminated impurities such as phosphorus from the iron. The smelters of the early fifteenth century already used the same method as did the smelters of the Forest

1 A. Quiquereu, 'Notice sur les forges primitives dans le Jura Berinois', Mitteilungen der Antiquarischen Gesellschaft in Zürich, vol. xvii, Heft 4, p. 78. Zürich, 1871. The bars discovered were tenoned at one end for insertion into a wooden shaft — Percy, pp. 297-298 (Catalan forge) — O. Krasa, in St E. (1931), p. 1289, referring to a furnace of the twelfth century in the Siegerland, Abbildung 4, shows a bloom on which impressions made by the bar are visible.

2 The camp is a rectangular enclosure of the Early Iron Age, VCH, Durham, vol. 1, pp. 344-345, 340-349.

3 Ibid., p. 354 (erroneously dated 1436). PRO, Durham Curator No. 37.
of Dean more than two centuries later, who added slag from old bloomeries; being well aware that such slag mixed with the ore imparts 'that excellent temper of toughness' by which their iron excelled.¹

Exactly as in pre-medieval iron-working a second process was required to make the crude bloom from the smelting or bloomhearth fit for use by the blacksmith. The bloom had to be consolidated by repeated hammering, with intermittent re-heating. In bloomeries equipped with not more than one hearth re-heating was carried out in the same hearth in which the crude bloom had been produced. The advantage of this was that a part of the heat which remained from smelting could be utilised.² Since, however, bloomeries equipped with two hearths were fairly general in the Middle Ages, the process of re-heating was conducted mainly in a second hearth, called a stringhearth. This term, first occurring in the accounts of Byrkeknott in Weardale of 1408, appears to be derived from 'stringing' which means making tense or tight. For generating the required temperature the stringhearth, like the bloomhearth, was equipped with its own pair of bellows. These bellows seem to have been larger than those of the bloomhearth, since a woman who helped to inflate them (folles sufflans) was paid more for labouring on the stringhearth. Altogether, operations at the stringhearth were considered more laborious than those at the bloomhearth, as is shown by the higher wages paid for the work.³ Manipulating the heavy blooms at hearth and anvil was strenuous. In addition, the operator was exposed to extreme heat at the stringhearth, since white heat (around 1400° C) was required.⁴ At Byrkeknott the work of the smith (faber) who operated the stringhearth is described as forging and purifying the iron (in fabricatione et purificatione ferri). Purifying was essentially extrusion of slag, but the small particles of slag and of iron which during the intermittent re-heating of the hammered iron fell from the surface of the iron into the hearth exerted, because of their high iron content, a purifying effect on the metal. In this way the process of refining cast iron by purifying in the slag bath was already begun in the bloomery. Finally the bloom was split (payments made to the smith: 'fabro fabricanti et in pecias dolanti').

An axe was used for splitting.⁵ The term covers two different operations, one of which was cleaving the bloom deeply, but without cutting it completely asunder, a practice fairly general in the Middle Ages. A

¹ Phil. Tr., vol. xii, p. 932.
³ At Byrkeknott the bloomer received 6d. per bloom for smelting, but the smith who operated the stringhearth 7d. for forging. Still more significant is the difference in the pay of the foreman who received 2d. per bloom when he helped the bloomer and 3d. for assisting the smith.
⁴ "The Flame or White Heat used when Iron has not its Form or size, but must be forged into both", J. Moxon, Mechanick Exercises, No. 1, p. 9. London, 1677.
⁵ An axe for splitting (securis pro ferro scindendo) is mentioned at Tudeley, in 1330. Arch., vol. lxiv, p. 157.
split bloom of iron smelted from Scandinavian bog ore is now at the Museum at Örebro.\(^1\) Three split blooms very similar in shape, each about 8 inches long and 11\(\frac{1}{4}\) pounds in weight, were found in county Fermanagh, Ulster. The macrostructure of the blooms is consistent with splitting at a high temperature which shows that it was cooled by air only and without quenching.

The object of this splitting was to test the quality of the iron. Exam-

\[\text{Fig. 17. Split bloom.}^2\]

From E. E. Evans.

\(^{1}\)Illustrated by Johannsen, Bild 94, p. 128. The splitting of a bloom with an axe is shown in an illustration (marked by the letter M) of a Swedish Osmund furnace, published by Percy, Fig. 27, p. 321, and by Johannsen, Bild, 93, p. 127.

\(^{2}\)E. E. Evans, 'Strange Iron Objects from county Fermanagh, Ulster', Archaeological Journal, vol. ii, pp. 58 et seq. Belfast, 1946. The exact weights of two blooms were 11 lb. 4 ozs. each and of the third 11 lb. 15 ozs. — Illustration on p. 60, ibid.
higher content of carbon at the outer edges probably indicates fortuitous absorption from charcoal during the intermittent re-heatings. Examination also disclosed that the metal was very free from non-metallic matter of any kind, and contained little slag.

Deep cleaving enabled the bloom to be broken in two. The sundered halves, however, were still too heavy to be handled by the blacksmith with ease, especially in the case of very heavy blooms such as those produced at Byrkeknott from the years 1408 to 1409 (le. 87 lb.). So, before the iron was ready for delivery to consumers, it had to be cut into smaller pieces. Presuming that the number of pieces into which the bloom was finally cut were the same as at Rievaulx, the bloom at Byrkeknott would have been cut into twelve pieces each weighing 16½ lb. which would be just right for making implements of a heavier type.¹ For small objects such as horseshoes, ploughshares, etc., pieces still smaller were required, but cutting them was mainly left to the blacksmith.

MECHANIZATION

The greatest advance in the medieval iron industry of Britain was the adoption of water as a motive power. Replacing manual by mechanical power, it represented a step in mechanization which was a decisive victory in man’s struggle with nature.

When the use of water power started in Britain is not known. An ironworks operated by water power in Eskdale, Cumberland, is claimed to be Roman, but the evidence is meagre and not convincing.² There is a possibility that the two mills referred to in 1086 as rendering blooms of iron were operated by water power, but this is doubtful. The first more cogent evidence in England is from a period shortly after 1200. By that time water power had been introduced in most of the chief iron-making regions of Europe, such as Styria, Carinthia, Bohemia, Lorraine, the Dauphiné in France, in Germany and in Scandinavia,³ and it is unlikely that the monastic orders, especially the Cistercians who played a prominent part in the erection of ironworks operated with water power on the Continent, would have failed to introduce such a useful device when they settled in England. The majority of their bloomsmithies were at sites where running water was available, but this is not conclusive, since water was used for various purposes in the process. However, actual evidence of the use of water power,

¹ At Rievaulx, in 1541, the bloom of 2½ cwt., or 288 lb. (108 lb. per cwt.) was cut into six pieces each of 24 lb., cf. App. VII — At Launceston in 1385, a heavy hammer-axe of iron, used for breaking stones at the quarry, had a weight of 16½ lb., and two new wedges had weights of 10 lb. each, which is the same as that of wedges used at the quarry of Stapleton, Yorks., in 1390. L. F. Salzman, Building in England, p. 331. Oxford, 1952.
² See above p. 48 — For the following see evidence in App. III.
though scarce, is not completely lacking. A conduit or goit, 5 feet wide, leading water to the forge of the Cistercian Abbey at Kirkstall near Leeds in Yorkshire, was built about 1200. A similar conduit was at Nogent-sur-Seine, in Champagne, where it definitely served to supply an iron mill. Further evidence, somewhat later and not quite so definite, is from one of the five bloomsmithies (fregiae) near Belper, in Duffield Frith, Derbyshire. One of them, and judging by the revenues yielded, the largest, was in Holland Ward, but had closed down by the following century. A Royal Commission which in 1581 inspected the locality in order to find suitable sites for lead mills, found large heaps of ancient slag near the brook and came to the conclusion that there had been 'some water worke there for the melting of Iron stone'.

There is nothing to show to what extent the new device was adopted in the thirteenth century. It may however be safely assumed that it was at least used in the larger ironworks, the so-called 'great forges'. This assumption is supported by a parallel development which affected the manufacture of cloth. Mechanizing of fulling began in England in the late twelfth century with the introduction of fulling mills (first in 1185). In the thirteenth century such mills were introduced all over the country.

The evolution of the ironmill proceeded rapidly after the Black Death of 1348, probably largely because the consequent shortage of labour made the adoption of mechanical devices more desirable than ever before.

The simplest contrivance in an ironmill operated with water power was used to work the bellows. An early drawing is supplied in a book of designs made between 1438 and 1441 by Marianus Jacobus called Taccola, a citizen of Siena in Italy, famous for his skill as an engineer which gained him the title of 'The Archimedes of Siena'. (Cp. Fig. 18.)

The wheel (A) represents the type which was most commonly used in Britain. It is called an overshot wheel because the water is 'shot' (i.e. discharged) over the top of the wheel. The water tapped from a river some distance away was first led in a leat to a pond where it was stored. From the pond it ran to the wheel through a channel called the head-race. The channel, either in its whole length or only at the end approaching the wheel, was a wooden trough with a sluice at one end which was operated by a cog on a shaft turned by a handle. If the sluice is down, the overflow of water runs through a shoot at the side

1 Paris, Archives Nationales, J 195, No. 34 (molenodium cum fossato ad quod ferramenta moluntur).
4 M. Berthelot, 'Pour l'histoire des arts mécaniques et de l'Artillerie vers la fin du moyen age', Annales de Chimie, 6 series, Tome 24, pp. 433 et seq. Paris, 1891 (Taccola's drawing is reproduced on p. 483, Fig. 96).

A drawing somewhat similar, first published by V. Biringuccio, Venice, 1540, is reproduced by Johansen, p. 93, Bild 59.
of the trough above the sluice. If the sluice is raised the overflow stops and the water, discharged from the bottom of the sluice to the top of the wheel, keeps it turning. By the quantity of water allowed to flow

Fig. 18. Bellows operated with water power, c. 1440.

from under the sluice the speed of the wheel can be regulated. The water falls into the wheel pit whence it is carried away by a channel called the tail-race that joins the river at a lower level.\(^1\) The slope of the tail-race must be sufficient to secure a constant flowing-off of the water,

\(^1\) Cf. Plate xvi which shows overflow, sluice, wooden trough, overshot wheel and wheel pit. A stone channel and wooden spouts for conducting the water to the wheel are referred to in 1408 at Byrkeknott, App. III.

L—H.I.S.
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so as to prevent any accumulation of water in the wheel pit which would slow down the wheel and cause loss of power. With the undershot wheel, rare in Britain, the water was discharged from a sluice at the bottom of the wheel and moved it from beneath.

The diameter of the wheel in the Middle Ages is not known, but it appears to have been well under 15 feet on the evidence from the bloomery site on the Holland Brook in Derbyshire. The Commission of 1581 proposed a site for a lead mill much lower down the brook, where the current was stronger. Since the wheel of a lead mill in Derbyshire erected in 1554 was 15 feet high, the wheel of the ironmill of 1256 must have been considerably smaller. The same applies to the bellows which in 1554 had a length of 12 feet.¹

Though smaller than in the sixteenth century, the bellows (EE) were definitely larger in the Middle Ages than in any of the preceding periods. A better blowing apparatus was necessary for the smelting of red haematite ore, for which the medieval ironmasters had a predilection. In the pre-medieval bloomery reduction of the ores, which were mainly brown haematites and bog ores, took place in the region of 1200°C. Red haematites, on account of their compactness, required a higher temperature² and more skillfully constructed bellows. They were the most expensive item in the equipment of the medieval forge.³ The modern type of heart-shaped bellows is said to have appeared even before the twelfth century.⁴

The bellows were set in motion by the shaft of the waterwheel. The shaft or axletree (B) turned on gudgeons (CC) or centre-pins fixed in its two extremities.⁵ Cams (DDD) fixed on the shaft animated the bellows. In Taccola’s drawing this was effected by pushing up the lower board of the bellows thus forcing air out through the nozzles (FF) into the tuyere (G) and thence into the furnace. When the cam had done its work and moved away from the bellows, the lower board fell by its own weight and air was drawn in through an air hole (not visible in the drawing). A more efficient tripping mechanism which appears to have been adopted widely by 1500 at least, operated in exactly the opposite way.⁶ They were worked by levers. A lower lever, when depressed by the cam, compressed the bellows, so that the air was driven through the nozzles. For the purpose of raising the bellows again an upper lever was employed. It was fixed at right angles across a large

¹ See Chapter 12.
³ In a forge at Beverley, Yorkshire, which belonged to the Knights Templars, a pair of bellows was rated at 10s. in 1309, which was almost double the amount paid for a horse (6s.). PRO, Exchequer Ancient Extents, No. 16.
⁵ II gogoyues ferri . . . pro fine del axletre rotae aquatiae, Byrkeknott, 1408. EHR, vol. xiv, p. 517.
⁶ Detailed description with illustration of the bellows (with all their parts) and the way in which they operated given by Agricola, pp. 365–371. See also below Plates xvi and xvii.
beam. The shorter end was above, and connected with the bellows by a rope; at Byrkeknot a rope when it broke was replaced by a sword blade (sweidblad pro les belowes) in 1409. The longer end was weighted with counterpoises, the weight of which was sometimes increased by hanging on it a box filled with stones or pieces of iron. In primitive bloomsmithies the upper board of the bellows seems to have been lifted by hand with the help of a rope, as shown on a woodcut illustrating the manufacture of iron in Sweden around 1500 and published by Olaus Magnus, Archbishop of Upsala. Possibly this simple method was used in small bloomsmithies in medieval England also.

Early evidence, though scanty, suggests that in the medieval bloomery water power was applied earlier for working the bellows than for moving the hammer. A much stronger framework was required for a heavy hammer, and only a hammer heavy enough to make very solid iron—more solid than could have been produced by man-power—would have justified the extra expense of a separate water conduit, wheel and axletree, in addition to those required for the working of the bellows.

In the few documents referring to waterwheels in English bloomeries around 1400 (App. III), never more than one wheel is mentioned. It seems impossible that a single wheel could have moved not only the two pairs of bellows for the two hearths, but a power hammer as well.

The blooms of the fourteenth century, which weighed less than 40 lb., could certainly have been dealt with by workers using the ordinary hammers of the period. Even later, when larger blooms were produced, blooms such as those produced at Byrkeknot in 1408 still weighed less than two cwts. (195 lb.), which was very much less than in other iron producing countries, such as Styria, in which water power is known to have been applied to hammering in the Middle Ages. It was by no means beyond the strength of the workers to lift a bloom of 195 lb. out of the hearth and drag it to the spot where it was to be hammered and split. Moreover there is evidence that very heavy hammers were in fact used without mechanical power, for example, a hammer weighing half a hundredweight, made in York in 1446 for stone-masons. A hammer head weighing about 80 lb. (40 kg.) was discovered at a forge at Lavoirs de Séprais, in the Bernese Jura, a centre of iron-working through the ages. A small rivulet was quite near the site, and it has been assumed that the hammer must have been operated by water power on account of its weight. However to assume that such weights

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2 Cf. Johannsen, p. 93.
3 Johannsen, pp. 131-132.
5 A. Queirerez, 'Notice sur les forges primitives dans le Jura Bernois', Mitteilungen der Antiquarischen Gesellschaft in Zürich, Band xviii, Heft 4, p. 83, Zürich, 1871, illustration Plate ii, fig. 9; Beck, vol. 1, p. 821 — The only medieval hammer head found in Sussex was
could not be handled by the medieval ironworker would be to under-rate his bodily strength. Iron crow-bars used for quarrying stone for Magdalen College, Oxford, which were certainly handled without water power, had similar weights (72 lb. in 1474, 91 lb. in 1514). 1

Actually there is nothing to suggest that water power was used to operate the hammer in medieval England, though this is not to deny that some sort of mechanization was applied to hammering. A device which partly replaced manual by mechanical power was the 'oliver', a treadle-operated tilt hammer.

Fig. 19. The 'oliver'.


The oliver had one arm attached to an axle worked with the foot by a treadle which brought the hammer head down on to the iron at the hearth of the forge. When the smith lifted his foot, a swing raised the hammer head ready for the next stroke.

An oliver is first mentioned in a deed of 1352 relating to a bloomery in Creskeld Park near Otley in Wharfedale, West Riding of Yorkshire; olivers were still in use in the West Riding at a few places in the nineteenth century. 2

dug up among the slag on the site of Roffey bloomery, near Horsham (see above Map I). Sketch supplied in Sussex AC, vol. xviii, p. 195, and by Straker, p. 442. Nothing, however, is known about the present whereabouts of the object.

1 L. F. Salaman, loc. cit., p. 331.

In addition, two olivers in the parish of Birstall, between Huddersfield and Leeds, are referred to in 1308, York, Diocesan Registry, R.VII, E.98. At Byrkeknott also the oliver may have been employed for hammering in 1408-09, since the name of the smith is identical with that of a smith who worked an oliver in 1375, according to the above-mentioned
OUTPUT, EXPENSES, AND PROFIT

Despite the scarcity of evidence it is not impossible to obtain some idea of the quantities produced in a small itinerant bloomery as well as in a permanent bloomsmithy.

An itinerant bloomery, operating around 1240 in the Barony of Coupland, Cumberland, required 24 dozen of ore to keep going for a year. The dozen as a measure for iron ore remained almost completely constant at 12 cwt. during the sixteenth and seventeenth centuries. Presuming that it was the same in the Middle Ages, the quantity of ore smelted would not be more than 14 tons 8 cwt. in the year. The ore was red haematite, the richest ore in the country. The yield of metal from the ore, however, was very low in the direct process conducted in bloomeries. A yield of 17½% from the rich haematites of Cumberland would be well within the mark. At this rate the output of the above-mentioned bloomery would be approximately 1 ton 14 cwt. per annum.

The output from permanent bloomeries, operating without the interruptions caused by removal to new sites, was greater. At Tudeley, in Kent, an annual average of 166–167 blooms was produced between 1330 and 1354. At a forge in the Lordship of Wark, in Tindale, Northumberland, it was approximately 167 blooms between 1333 and 1353. If the time of working is taken into account (Tudeley), production was one bloom per day. Accepting the weight of a bloom as 32½ lb. (see below note 3, p. 140), the average output at Tudeley was 2 tons 10 cwt. 26 lb. a year; at the Northumberland forge it was 1 lb. more. The figures may be taken as typical for an English bloomery of medium size in the first half of the fourteenth century. In the preceding boom...
period between 1250 and 1300 production may have been higher, but it is doubtful whether even then it exceeded an annual average of 3 tons per ironworks.

Around 1400, when water power was adopted more generally, production was very much higher. At Byrkeknott, in 1408–09, 278 blooms (of 195 lb. each) were obtained from smelting which works out at 25 tons 2 cwts. (approximately one bloom per day). Of the 278 blooms 254 with a total weight of 22 tons 18 cwts, 65 lb., were converted into 204 blooms of forged iron weighing 18 tons 8 cwts, 33 lb. This works out at a ratio of approximately 11 to 9, which compares favourably with the ratio of 4 to 3 in the bloomeries of the late sixteenth century, and was probably due to the admixture of cinder during the smelting process.

Prior to the Byrkeknott accounts no evidence is available which gives the exact weight of the bloom in the preceding centuries. Figures of charcoal consumption at Tudeley, Kent, suggest a weight of approximately 30 lb., which agrees fairly well with other evidence also from Kent. In 1323, 26 blooms of iron obtained in the preceding year were in the store at the castle of Tonbridge, in Kent. They were cut into 423 pieces and sent to London. Taking the piece at 2 lb. in weight, the weight of the bloom works out at 32\(\frac{1}{2}\) lb.

At ironworks such as Tudeley which was worked for the owner, the profit was high: 31% in 1330–34, and 23% in 1350–54. The main reason was that wood and ore were supplied free of charge from the owner’s estate. Despite this advantage the expenses for charcoal was the biggest item in the accounts. The cost of converting the wood into charcoal and of carriage to the forge amounted to half of the total working expenses. The second largest item (about one third of the total) was the wages and salaries of the permanent workers. The cost

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1 Up to the fifteenth century the cwt. was 108 lb., but later it was gradually superseded by the London cwt. of 112 lb., Rogers, vol. i, p. 197; vol. ii, p. 209. In the bloomery the older cwt. was retained, App. VII.


3 In fourteenth-century England iron was mainly sold by the dozen (duodena) containing six pieces (earliest reference in a statute ascribed to 1302–03, Statuta, vol. i, p. 205). In building accounts of Corfe Castle, in 1363, the price of the dozen indicates that its weight was, as we might expect, 12 lb., which makes the weight of the piece 2 lb. (Salzman, Building, loc. cit., p. 287).

There is evidence of a similar weight in the thirteenth century. The bloom from Downpatrick, Co. Down, Ulster, which is a rectangular oblong piece of iron 2 x 2 x 8 inches showing marks of cutting with a sharp tool, weighs a fraction more than 1 lb. 7\(\frac{1}{4}\) ozs. (now in Belfast Museum, evidence kindly supplied by B. Proudfoot, Esq., of Queen’s University, Belfast. Analysis, App. I). The piece is much corroded, which accounts for its weighing less than 2 lb. Quarrels, i.e. iron bolts for crossbows made for the Royal Castle of Ayr, in Scotland, in 1264–66, weighed 13 lb. each (1,770 made from 220 stones of iron), The Exchequer Rolls of Scotland, vol. i, pp. 5–6, Edinburgh, 1878. Allowing for loss in forging, the piece would have weighed about 2 lb.
of digging and dressing the ore and of conveying it to the works amounted to 15% of the total. A very small proportion was for repairs and other extraordinary expenses. Expenses were considerably higher at rented ironworks, since the raw materials had to be bought, or paid for in high rents.

The substitution of hydraulic for manual power made the operation of a bloomsmithy much more economical, since it saved labour. At a works at Treeton in Yorkshire, south-east of Sheffield, which had a bloomhearth and a stringhearth each equipped with a pair of bellows and one waterwheel, only three ironworkers were employed in 1507 to work the two hearths. At the bloomsmithy of Llanrisant in Glamorgan, newly erected in 1530 but operated without water power, three times as many men were required to work the two hearths, of which as many as four were needed to operate the bellows.

SMITHCRAFT

The principal consumers of iron from the bloomery were the numerous blacksmiths in villages and manors, in castles, and in the cities and towns.

The most important craft in the agricultural community was that of the smith. Every village needed the services of a skilled man to make and repair the shares and coulters for the ploughs, harrows, and other implements; to make horseshoes and shoe the horses. Some of the implements ready for delivery are enumerated in an early inventory relating to one of the forges worked on the manors of the Knights Templars in Yorkshire, in 1309. They comprised sickles, harrows, pronged forks, rakes, and iron parts for carts.

Each castle also had its own smith. An inventory of 1325 relating to the forge at Tonbridge Castle, in Kent, suggests that it was mainly used for farriery. An essential work of the castle smith was forging quarrels, i.e. iron bolts for crossbows. E.g., in 1264–66, 1770 bolts were made for the Royal Castle at Ayr, in Scotland.

In cities and towns the blacksmiths shared in the prosperity and importance of the medieval crafts, organised in the Guilds which in many of the large cities of Europe and in a great number of smaller towns temporarily wielded the whole power of municipal government.

The Guilds or Companies of London came into existence at different periods. Power to control a trade was first approved by the Mayor and

1 Straker, p. 194.
2 Bo., MS Top. Yorks. C. 36.
3 See p. 146, note 3, Chapter 9.
5 PRO, Exchequer Ancient Extents, No. 16.
6 VCH, Kent, vol. iii, p. 386.
7 See p. 140, note 3.
after application a Royal Charter would be granted. It conferred upon the Guild certain powers and privileges, and also required the performance of certain duties, such as the obligation to care for the Guild's own poor, to protect the public against bad workmanship and any form of knavery which might be practised by irresponsible traders, and to maintain good conduct generally among the members of the Guild. The Blacksmiths' Company of London, officially known as the Tooth-Drawers in the thirteenth century, was incorporated in 1325 by prescription, and subsequently by Royal Charter in 1372. 1

In the fourteenth and fifteenth centuries the manufacture of ironware in Yorkshire centred in the city of York. Chaucer's picture of the miller of Trumpington with his 'Shefeld thwitel in his hose' supports the claim that a flourishing cutlery industry existed at Sheffield in those days. However, the Poll Tax returns of 1379, though referring to a number of cutlers at places in the district—Ecclesfield, Handsworth and Sheffield itself—do not indicate that the manufacture of cutlery in the region was on a large scale. 2 York's most formidable rival in metal-working was Coventry which in the fifteenth century had a considerable wire industry. 3 The most important of the metal-working crafts in Bristol was that of the wire-drawers, which absorbed some of the smaller crafts, such as pin-making, and the trade was granted a Royal Charter in 1469. 4 The earliest reference to smiths in Scottish craft associations occurs in a document of 1427. 5

Some of the smiths are known to have attained to wealth and position. Henry of Lewes, the King's master smith, owned considerable property. When he died in 1291, he left to his wife and daughters houses in the City of London, at Lewes, and at Seaford, in Sussex. 6 Henry first appears in the palace accounts of 1259. He worked for the King up to the end of his life. The year before his death, he was paid for ironwork for the tomb of King Henry III. On this altar-tomb, which is in the Chapel of St. Edward the Confessor in Westminster Abbey, the large slabs of red porphyry at the sides are kept in position by foliated iron clips. 7

1 The name 'Tooth-Drawers' seems strange, but the Blacksmiths' Company, at various times, controlled a number of trades not closely associated with smithcraft — A. Adams, The History of the Worshipful Company of Blacksmiths, pp. viii, 12. London, 1937 — Unwin, loc. cit., p. 68.
The forge of an English blacksmith of the Middle Ages is shown in Plate XIV. In Plate XIV, which is from the Holkham Bible made in southeastern England, it is not the smith himself but his wife who forges the iron. The illustration represents a scene from the 'road to Calvary'. The smith who is ordered to make the nails for the cross, refuses under the pretext that his hand is injured. When he is told to show his hand, his pious falsehood is made retrospectively true.

The method of forging the iron bar into objects for use or for decorative purposes was still to forge the iron while hot. The tools were the same as those used in earlier centuries, but from the thirteenth century onwards dies for stamping were employed, which was a first step towards mechanization. Stamped work was produced by hammering the hot iron into the prepared die. The use of stamping-dies became necessary when the smith began to use decorative designs from nature, such as the vine-leaf pattern. This pattern is lavishly employed in the best-known specimen of all the early English grilles, that on the tomb of Eleanor of Castile, wife of Edward I, in Westminster Abbey (Pl. XV). It was made by Thomas de Leghtone, a native of Leighton Buzzard, in 1294.

The grille consists of eleven panels resembling hingework. They are riveted to the face of a plain rectangular frame which is surmounted by a row of three-pronged spikes. No two of the panels are completely alike, but in nine of them the vine-leaf pattern appears. In two others growing corn is represented. The stamp for the vine leaf was also used to finish off the corn.

The method of forging the iron hot still continued in the thirteenth century, but around 1300 it began to give place to a new method of working. The smith ceased to depend upon hammer and heat, and began instead to work the cold iron with the help of new implements such as the saw, file, and drills, and with rivets and bolts.

OUTLINES OF DEVELOPMENT

As we have said, the iron industry in the twelfth and thirteenth centuries showed several striking developments. The field of mining operations was extended to new ironstone beds, especially in the north of England. Their ores, previously hardly at all exploited, required a stronger blast, which made it necessary to improve the blowing apparatus, and—at least in large bloomeries—to apply hydraulic instead of manual power to the bellows. Also the method of smelting in one hearth, and working up the bloom in another, came increasingly into use.

1 Another picture, also of the fourteenth century but somewhat later, is published in Jo., vol. 161, p. 326.
The fourteenth century was a period of transition in various respects. With the substitution of cold-treatment for heat-treatment in smithing the blacksmith no longer relied exclusively on the forge and hammer, but had to adopt the tools of the locksmith and the armourer. Application of heat became confined to the preliminary stages, while the major part of the work was accomplished by handling the cold iron and applying the file and the saw, or by embossing.¹

In the production of raw material a marked change can also be observed. The monasteries lost their previous position as prominent iron-producers and confined their activity mainly to working the iron in smithies annexed to the monasteries for agricultural implements and the repairs of buildings. The bloomeries came increasingly into the hands of lay owners who sold their products to ironmongers in the towns. The ironmongers resold it to the crafts who had a monopoly in the manufacture of iron ware. The shortage of man-power resulting from the 'Black Death' caused a general rise in prices, noticeable in agriculture as well as in the crafts and in industry. Particulars as to the effects of this on the iron industry are provided by the accounts for the Tudeley ironworks, for the periods 1329–34 (before the plague) and 1350–54 (after the plague).² Previous to the plague the average price of iron had been fairly constant at 1s. 8d. per bloom, but afterwards the price rose to, in some cases, more than double this figure. The iron-workers' piecework rate of 5½d. per bloom increased to between 7½d. and 9½d. over the same periods. The average of prices and wages thus approximately doubled.

When the high consumption of iron by the mainly agricultural population of the realm at the time is considered, the sudden rise in price was bound to have serious economic effects. The government, well aware of the gravity of the crisis, attempted to alleviate the situation by legislation aiming at control of labour and prices, and at prohibition of the export of iron. By a statute of 1354 the export of iron was forbidden and its sale at excessive prices made a punishable offence.³

The statute illustrates the gravity of the crisis, but it no more succeeded in controlling prices than did other enactments succeed in controlling labour. All over the country the labourers realised the opportunities offered to them by the shortage of man-power, and crowds left their places of employment in search of higher wages. This caused the first great struggle in English history between capital and labour.

¹ Gardner, vol. i, pp. 92, 99, 112.
² Arch., vol. 64, pp. 145-164.
³ Statutes, vol. i, p. 345. Exceptions, however, were made particularly regarding iron produced from ore of superior quality such as the red haematites of the north. In 1355, e.g., two merchants of Liverpool and the Abbot of Furness obtained permission for exporting Lancashire iron to Ireland, Cal. of the Patent Rolls Edward III, vol. x, pp. 267 and 299. London, 1909.
The Medieval Bloomery

The repercussions of the acute shortage of labour were felt in the iron industry as much as in any other department of industrial activity, but the ultimate effects upon the industry were beneficial, since it became absolutely necessary to off-set the labour shortage by improving methods at every stage from raw material to finished product. Thus coppicing became very general in the late fourteenth and fifteenth centuries; hydraulic power was applied to smelting in an increasing number of ironworks after 1350, producing larger blooms with less manpower. By 1450 at latest, the iron industry appears to have recovered completely from the effects of the Black Death. With the renewed growth of population the demand for iron increased; so much so that in spite of improved techniques production remained unable to meet the demand on the home market and had to be supplemented by large imports from abroad.
CHAPTER IX

THE FINAL PHASE OF THE DIRECT PROCESS

THE SITUATION AFTER 1500

The direct process of producing malleable iron was still extensively used in the sixteenth and seventeenth centuries. Wherever landowners and ironmasters introduced the indirect method, first producing pig iron in the blast furnace, iron was still being made by the older method conducted in bloomeries.\(^1\) Even new bloomeries were erected during this period.\(^2\)

Although water power for blast production had been widely adopted by 1500, bloomeries with bellows worked by hand continued to be operated. A bloomery of this type was erected as late as 1531 in the Royal Park of Clun near Llantrisant in Glamorgan a few weeks after the mining of haematite ore in the vicinity had started.\(^3\)

The ore was carried on horseback from the mine to the smithy for smelting. Blast was produced by bellows worked by four 'blowers', three of whom worked at a time while the fourth stood ready to replace one of the others. The most important of the workers at the bloom hearth was a fifth man called the 'fewar', i.e. the fireman who 'kepith the fire' to melt the ore; he received a higher wage than the others (12d. instead of 7\(\frac{1}{4}\)d. per day). Evidently he was the bloomer in charge of the smelting process. Twice a day a 'gad' of iron, i.e. a bloom weighing 1 cwt. was produced, which took from six to seven hours. After it was extracted from the hearth, the four bloomers acted as 'hewers', i.e. they consolidated the bloom by hammering, and probably also cut it.

\(^1\) For details see below Chapter 11.
\(^2\) E.g. in 1542 near Riom Bridge, in Cannock Chase, Staffordshire, Stafford, Wm. Salt Library D 1734 — A 'new' smithy at Himley, Staffordshire, referred to in 1585, Dudley Papers, Box 19, Bundle 32 — A bloomery was erected near Hailemere, Surrey, in 1603, which was in the peak period of blast furnace production in the Wealden iron industry, VCH, Surrey, vol. ii, p. 271.
The expected (nominal) yield of iron from the ore was 1 cwt. 'or somewhat more' from 3 cwts. of ore, which is about 35%. It is, however, very doubtful whether such a profitable yield really was obtained, since every day 16 cwts. of ore were carried from the mine to the bloomery and only 2 cwts. of iron were produced by smelting, which suggests a yield of not more than 12¼%. A yield so much lower than expected would be in keeping with a report made in 1531, when a Royal Commission surveyed the bloomsmithy and arrived at the conclusion that working was very unprofitable. An Italian by the name of Marcho Raphael who was on the Commission examined the slag and found a great loss of iron caused by insufficient reduction of the ore. He declared his willingness to propose an alteration which would 'save all the iron in the synders' (i.e. slag) and would make it possible to reduce the number of workers engaged in the process of smelting from five to two.1

The immediate result of the examination and of the proposals is not known, but in 1540 mechanization was achieved by the introduction of water power. At about this date William Kendal, a landowner at Launceston in Cornwall, was granted the right to mine ores of iron and other metals within a three-mile radius of Clun Park. He also obtained a licence to make ponds to supply with water all kinds of mills which were to be erected for 'blowing, blooming, fining, and trying' the ores of iron and of the other metals he was to exploit.2 The grant indicates a new bloomery, this time operated with water power. It was worked for four years, but evidently no profits were made from it. Kendal was already in financial difficulties when he established the improved bloomery. He owed large sums to London merchants one of whom, John Sadler, Alderman of the City of London, had him imprisoned for debt and installed Thomas Davye of Cranbrook, in Kent, as overseer of the works and the iron mine.3

There is no evidence in contemporary records concerned with bloomeries that water power was extended to the working of the hammer either in Clun Park or elsewhere. At a bloomery in Bilsdale in Yorkshire a treadle-hammer was still in use in 1541.4

At that date, however, a different improvement was introduced, namely hammer mills for the final working of the blooms.

THE HAMMER MILL

In documents and inventories relating to the first blast furnace and power forge erected in 1496 at Newbridge in Sussex, there is special mention of a 'great water hammer'. Such a hammer was apparently

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2 PRO, Ministers' Accounts, Henry VIII, No. 7493; 'fining' apparently refers to lead, since there was a lead mine in addition to the iron mine in 1531.
3 PRO, Chancery Decree Rolls, Roll I, No. 74.
4 Inventory, App. VII (reference to treadle pins).
The Final Phase of the Direct Process

considered a novelty and appreciated as an improved device for making malleable iron. Even before blast-furnace production expanded outside the Wealden area, the power hammer found its way into regions in which the bloomery process still was the sole method employed. The first who introduced it was the same hammersmith who had worked the first hammer of this type at Newbridge. He was Lambert Symar (or Seimar, in the later version of the name), one of the earliest French ironworkers to come to England.

In 1538 Symar was tenant of an iron mill, or bloomsmithy, situated at Rievaulx. The ancient Cistercian Abbey of Rievaulx in the North Riding of Yorkshire had two bloomsmithies at the time of the Dissolution of the Monasteries. One was to the south, the other approximately five miles north, of the Abbey in Bilsdale at a site called Laskill. Each of the two smithies had a bloomhearth and a stringhearth.

In 1540 a substantial re-building took place at the bloomsmithy south of Rievaulx Abbey. The water supply was increased by strengthening and heightening the dam of the pond, so that the water was sufficient to serve a wheel for the bellows of two bloomhearts instead of one, and also a wheel for those of the stringhearth. The most important innovation was the installation of a water-powered hammer.

The weekly output of bloomhearts and stringhearts was one seam of iron at 16 cwt. equivalent to six blooms, so that on every day of the week one bloom was produced. The normal weight of the bloom was 2¼ cwt., but occasionally heavier blooms weighing from 3 to 3½ cwt. were also produced—much heavier than the blooms produced without water power in 1531. To produce six such blooms eight fother of ore (at 24 cwt. each) were used, which represents a yield of iron from the ore amounting to not more than 12%. Compared with Llantrisant the yield had not improved, but allowance must be made for the poorer quality of the ores exploited in the vicinity of Rievaulx, which were much leaner than the Glamorgan haematites rich in iron contents. The final output of forged iron was one ton per week (of six working days), much more than at Llantrisant (12 cwt.) or in other contemporary bloomeries worked with more primitive appliances. Allowing for the loss of time on account of the many Saints' days and festivals

1 Straker, p. 248 — App. VI — The water hammer used at the forge at Rievaulx was still spoken of as the 'great hammer' in 1576, Be., No. 527 — Illustration of water hammer see below Fig. 33.
2 See Chapter 10. In a contract of 1541, he still signed in French: ‘de per moi’, followed by the name, App. VII.
4 For the following see Be., Misc. MS 166, and App. VII.
5 E.g. at Goodrich, Herefordshire, 2 tons per month. Hereford Public Library, Court Rolls of the Manor of G.
and the occasional breakdowns of wheels etc., the annual output of the works may be estimated at about 45 tons.\(^1\)

The hammer mill was soon adopted at bloomsmithies in the Midlands. In 1549 Henry Grove possessed a hammer mill in Handsworth, Staffordshire.\(^2\) Another 'hammer smithy' was in operation at Oakamoor before 1577, at which date Nicolas Lesett passed on his lease to Richard Weston and Peter Growt, to be free to build a new hammer for Sir Francis Willoughby, which was probably a fore-runner of Sir Francis' forge at Hints in Staffordshire.\(^3\) Because of the increasing number of power hammers, unworked blooms each weighing as much as 4 cwt. and blooms worked up in the stringhearth weighing 3 cwt. were produced in the Midlands in the 1570's. The time required for smelting such blooms was twelve hours and for working them four hours. The higher production, however, was by no means general, either in the sixteenth or in the two subsequent centuries.

HEARTH AND PROCESS

The only description we have of a late bloomery hearth and the process conducted in it comes from 1675, referring to Milnthorpe Forge in north Lancashire. The description is contained in two letters, the second of which is a corrected version of the earlier one.\(^4\) There is a striking similarity to a sixteenth-century bloomery hearth described and illustrated by Georgius Agricola, the 'Father of Mineralogy'; the dimensions of the flat top of the hearth (A) are approximately the same, i.e. almost 5 ft. square.

As mentioned above, the hearth (A) was approximately 5 feet square. According to Agricola it was about 3 feet 3 inches high, but apparently higher in England in 1675 (4 4\(\frac{1}{2}\) feet). A crucible (B) was in the centre which, by Agricola's statement, was about 1 foot deep and 1\(\frac{1}{2}\) feet in diameter. The bellows were placed behind the back wall of the bloom-smithy. The bloomer with his left hand controlled the water supply, so as to regulate the blast. His mouth and nose were protected by a

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\(^1\) This is in keeping with other bloomeries operated with water power, such as Treeton near Handsworth, south-east of Sheffield, in 1597 (41 tons 12 cwt.), Bo., MS Top. Yorks. C.36. The bloomsmithy was still operated in 1559, Ecclesfield Parish Registers.

\(^2\) Cal. of the Patent Rolls, Edward VI, vol. v, p. 333. London, 1926 — Gr. had been engaged in 1543 by Wm. Wirley of Handsworth at his bloomsmithy at Perry Barr, Staffordshire, as an 'iron bannyer' for the 'brannying and working of every branme of iron which should be wrought ther', PRO, Early Chancery Proceedings, File 1170, No. 101.

\(^3\) HMC, Manuscripts of Lord Middleton, pp. 494-495, 554-555 (the date of 1579 is an error; in the original it was added later; the source was an account book commencing 28th August 1574, Middleton Papers) — R. A. Pelham, 'The Establishment of the Willoughby Ironworks', University of Birmingham Historical Journal, vol. iv, No. 1, pp. 19-21. Birmingham, 1953 — For Oakamoor see also PRO, Chancery Proceedings, Elizabeth Ann No. 39 and W 9 No. 21 (the bloomsmithy belonged to the Earl of Shrewsbury and the hammer to Simon Hering).

\(^4\) App. XIII, the earlier letter is of 12th August 1675, printed in Phil. Tr., vol. 17, p. 697, and by Fell, p. 204.
Fig. 20. Bloomsmitry about 1550.
From Agricola, p. 422.
(A) hearth; (B) heap; (C) slag-vent; (D) iron mass; (E) wooden mallets; (F) hammer; (G) anvil.
cloth against smoke and gases. The crucible was filled with charcoal heaped high up above it. The ore was placed in small pieces all round it, so that it was roasted first by the heat from the charcoal fire. The ore in small quantities was gradually pushed into the burning charcoal which was constantly replenished by new charges when it had subsided. The liquid slag ran out through a slag hole (C) which was otherwise kept closed by a clay stopper. The process of smelting took twelve hours, in which 1 cwt. of iron was produced. The bloom produced was in a pasty state. It was extracted with tongs and taken to a hammer moved by a water wheel.

The second part of the process was apparently carried out in a slightly different way in the late English bloomery. The bloom (D) was not beaten first with sledge hammers (E) as described by Agricola, but was carried immediately to the power hammer (F) and anvil (G). There it was consolidated by squeezing out the slag, and hammered into the shape of bars. Several hammerings were required with intermittent re-heating, which took place in the bloomhearth in which the smelting had been done, not in a second hearth. This is expressly stated in the first of the two English descriptions of 1675.

Compared with the preceding century advances seem to have been made in the general equipment of the bloomery hearth. The walls of the crucible and also the top of the adjoining parts of the hearth were

![Diagram](image)

**Fig. 21. Bloomery hearth at Garstang.**
From Lewis, vol. iv, facing p. 76.

protected by iron plates, which device was apparently adopted from the contemporary finery hearth used in the indirect process for re-melting the pig iron obtained from the blast furnace. A hearth of this protected type was at a bloomery operated in the eighteenth century at Garstang, between Preston and Lancaster on the ancient road to Scotland.

Little is known of the existence of this bloomery apart from a brief
remark in Bishop Pococke's travel diary.1 Passing through Garstang in 1756 he observed 'the smoke of some smelting-houses, which are erected there'.

Diagram (a) is a ground plan of the 'fire-place', i.e. the rectangular cavity in which smelting was done: (b) shows a section of the front of the bloomery. The small size of the fireplace and the position of the bellows, more towards the place where the worker stood, make it very like the contemporary English finery hearth.2

ADVANTAGES AND DISADVANTAGES

The long survival of the direct process conducted in bloomeries was by no means confined to Britain. Bloomsmithies were operated in various countries on the Continent until well into the nineteenth century.3 In rural districts with a limited demand, and particularly in remote parts with conditions unfavourable for transport, their position was secure for a long time. Nevertheless the direct method would not have lasted for such a long time if it had not had positive advantages. Iron made in the bloomery was usually of superior quality. Since on account of the lower temperature no fusion took place, as in the blast furnace, the iron remained free from those damaging impurities such as phosphorus and sulphur which get into it in the process of fusion. For this reason a pure iron was obtained even from bog ores despite their high content of phosphorus. Bog iron ores were not used in the blast furnace; this is clearly shown by the fact that in regions in which bog ores were smelted extensively in bloomeries as in Scotland and Ulster, blast furnace production relied on imported ores. Initial expenses for erecting a bloomery were very much less than those for building a blast furnace with fineries, chafery and a power hammer.

Still, the advantage of a comparatively small capital investment was outweighed by the better yield of iron from the ore and the lower consumption of charcoal per given unit,4 and eventually the disparity of

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2 Cf. App. XV.
3 E.g. in Carinthia and Styria, in the Austrian Alps; in North Germany (Harz Mountains) until the middle of the eighteenth century, in Upper Silesia until 1798, Neumann, p. 13 — In Finland, Percy, p. 325 (1864).
4 The yield from the red haematites of north Lancashire, in 1675, was 33% in the bloomery process (Fell, p. 204), but the same ore yielded in the blast furnace from 46% to 66% (see below p. 245). The yield appears rather high; the evidence is dubious, since the writer admitted that he was not always 'clearly informed' — For the low yield obtained at Llantrisant in 1531, despite the brown haematite rich in iron, see above p. 148 — See also p. 139, note 3. — At Tarnowitz in Upper Silesia (Poland) the yield of iron from the local siliceous brown haematites was 41% lower and the consumption of charcoal approximately 30% higher per cwt. with producing wrought iron by the direct method than with producing it by the indirect method, in the late eighteenth and early nineteenth century, B. Karsten, Handbuch der Eisenhüttenkunde, vol. iv, pp. 290–292. Berlin, 1841.
The Final Phase of the Direct Process

production made the bloomeries unable to maintain their former position in the economic life of the country against the competition of blast furnaces with their constantly increasing output. A bloomsmithy of average size produced less than a very small contemporary ironworks equipped with a blast furnace.\(^1\) The more the demand for iron increased, the more expanded the indirect method of producing cast or pig iron first and then converting it into malleable iron.

It will be shown in the two subsequent chapters how the direct method conducted in bloomsmithies was gradually superseded by the new indirect process which step by step expanded over the whole of the British Isles.

\(^1\) Comp., App. IV.
PART TWO

THE INDIRECT PROCESS
CHAPTER X

INTRODUCTION OF THE INDIRECT PROCESS

A NEW period in the history of ironmaking in Britain began with the introduction of blast furnaces. A blast furnace is a furnace of considerable height fed at the open top and continuously producing metal in a liquid form which, at the bottom, is tapped from time to time.¹

The substitution of the blast furnace for the bloomsmithy or bloomery meant an essential alteration in the process of producing malleable iron. Up to then, iron had been produced directly from its ore in one process conducted in two consecutive stages. It was reduced from the ore to a bloom or mass of malleable iron in a pasty or spongy state, and afterwards reheated and consolidated by hammering. Instead of obtaining malleable iron (with 0·1% carbon or less) directly as in the bloomery, in the blast furnace a highly carburised cast or pig iron (2·2% C., 4 or 5% C.) was produced first. It was actually a new metal, an alloy of iron and carbon which was too brittle for the smith's hammer. For this reason it had to be decarburised by oxidation or, to use the proper term applied to the process, it had to be 'fined' which meant refined, or freed from the surplus of carbon and other impurities acquired during the smelting process in the blast furnace. Refining was effected by smelting the pig iron down again in a proper hearth termed a 'finery' (derived from French 'affinage') before the iron could be drawn out and shaped by the forge hammer. With the refining of cast iron a new intermediate stage was introduced between the two stages of smelting the ore into a bloom and hammering the re-heated bloom, which had

¹ Based on Rhys Jenkins' definition in Nees. Tr., vol. i, p. 18. The term 'blast furnace' is generally accepted for this type, although it does not sufficiently express the characteristics by which the blast furnace is distinguished from older types such as the bowl-furnaces and the Continental Stückofen (high bloomery furnace), as blast was applied with all of them. The terms used in France and Belgium ('haut fourneau'), and Germany ('Hochofen') indicate the greater height compared with that of more ancient furnaces, which obviously impressed contemporary spectators.
sufficed in the direct process of the bloomsmithy. For this reason, the new process is termed the 'indirect process' of producing malleable iron.

THE EARLY IRON PLANT

The new process required a larger and more complicated plant. The use of water as motive power made a local separation of furnace and forge inevitable, since they required separate water wheels for blast production, one for the furnace, and one each for finery, re-heating hearth—termed 'chasery' (from the French 'échauffeur')—and power hammer. For this reason the forge was erected at a different place which, if the same river supplied the water power, was frequently a fair distance lower down, where a greater volume of water was available.

No illustration representing an early English iron plant or parts of it such as a furnace or a forge is in existence.1 Blast furnace and finery were introduced into England from the Continent where they were in use within a region extending from Brittany, over Normandy into the former French province of Picardy (now partly French and partly Belgian).2 In view of this we may take it that the English ironworks of this period was very similar to the one shown in a painting by the Flemish artist Henri Blès. Blès was born about 1490 at Bouvignes not far from Dinant on the river Meuse, and is supposed to have died at Liège about 1550, his first and only dated painting being of 1511. It is generally accepted that his industrial paintings represent ironworks operated in the Walloon country extending from Liège to Dinant and farther south-west into France, as he had seen them in his youth before he left, still a young man, for Italy.3 Another reason, in addition to their date, for believing that his pictures show iron plants very like the early English type is that they depict fineries adapted to the so-called Walloon process which was conducted in England exactly in the same way as in the country of its origin.4

Mining and dressing of the ore

Blès's picture (frontispiece) illustrates the whole process of obtaining iron from ore, although in some of the details the artist has taken

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2 J. Philippe, La contribution Wallonne à la peinture dite flamande, p. 15. Liège, 1908—J. Helbig, L'Art Mosan, pp. 136-147. Bruxelles, 1906 (facing p. 140, the painting preserved at Florence is reproduced the same as in frontispiece). Four other paintings, with the same subject, are reproduced from the originals at the Museums of Budapest, Graz, Prague and Vienna by A. Danay, Henry Blès, peintre de la réalité et de la fantaisie, Études d'Histoire et d'Archéologie Namuroises, dédiées à Ferdinand Courtoy, pp. 619-626, Namur, 1932, and by R. Evrard, Les Artistes et les Usines à Fer, Figs. 15-19, Liège, 1955.
3 Percy, p. 599. For details, see below, Chapter 16.
liberties so as to produce a greater artistic effect at the expense of reality. To illustrate the work of the miners as completely as possible, he has depicted three pits very close to one another (at the lower right-hand corner of the picture). It is difficult to imagine how they could be worked without breaking down, as such pits widened underneath into bell-shaped cavities or led into horizontal level drifts. Each of the two pits in the front of the picture is surmounted by a winch or windlass worked by hand and with a rope with a tub at the end. This was both for haulage and for the descent and ascent of the miners. In the pit to the left a miner is seen on his way up or down. He wears the typical miner's cap and holds a pick. The flat end served as a hammer for driving wedges into the rock to break it. At the extreme right corner of the picture workers are dressing the ore. One is breaking it with a sledge hammer into pieces suitable for charging into the furnace, another is sifting it to separate the larger pieces from the smaller. Further to the left a worker is seen washing the siftings in a basin the sides of which are of wooden planks.

The Furnace

After dressing, the ore would be wheeled in barrows to the blast furnace, which is seen in the centre of the picture, being equipped with a pair of bellows worked by a water wheel. At the rear of the furnace a broad stone stairway (not visible) would have led to the top. It served for carrying up ore and charcoal in baskets for charging the furnace. At the right of the furnace and rather in the background a woman is seen carrying, presumably towards the stairway, a basket filled with charcoal which she has apparently taken from the house behind, which seems to be the coal house. The thatched house in the centre is the furnace house or casting house. (Despite the danger of fire caused by sparks from the open top of the furnace, roofs thatched with straw were still used in Sussex at a comparatively late date.) The furnace house also contains a chamber, the door of which is seen at the right end of the house. The chamber would have served as a store for implements, and also to provide sleeping accommodation for furnace workers, in particular for the founder. (As he was responsible for the efficiency of the furnace, the founder's constant presence was required during the smelting process.) The blast furnace is almost concealed by the furnace house; only the top and the lowest part of the front are visible. The top shows the square shape of the outer casing. Flames are issuing from the top aperture and from the front of the hearth at the bottom of the furnace. The picture represents the moment at which the tapping of the molten iron has just finished. It is running into a long narrow furrow prepared in a bed of

1 For details, see below, Chapter 13.
2 In the winter of 1698–99, e.g., straw was carried to the furnace at Waldron, in Sussex, to make 'g square of rose upon ye furnace howse'. BM, Add. MS 33,156, fol. 101v.
sand in which it consolidated. The end nearest to the furnace is still glowing. (The long piece of cast or pig iron acquired a triangular shape from the furrow, flat on top and tapering at each end to a blunt point. In England it was generally termed a 'sow', if the weight was above 10 cwt., if below, it was termed a 'pig' from which the present term 'pig iron' is derived. Only in Sussex, in which the blast furnace was first introduced from France, the French term 'geuse', or the English 'goose' was still occasionally used as late as in the seventeenth century.\(^1\)

To the right of the furnace house several workers are seen carrying a sow to a balance. A balance or 'iron beam' was an object of great value in sixteenth-century England and was mostly imported from abroad.\(^2\) It had to be very strong to carry the weight of a sow.

**The Forge**

After being weighed the sows are conveyed in a wagon drawn by horses (in England oxen were often used), to the forge which is seen on the left side of the picture. The three essential parts of the forge corresponding with the three stages of the process of converting the cast iron from the furnace into malleable iron are depicted. They are (from right to left) the finery, the power hammer and the chafery. To enable the spectator to see the various operations at the forge, the artist lets him see right into the interior of the building. The open hearths of finery and chafery are surmounted each by a huge chimney. In England structure and shape of the chimney were more of the kind which is shown above the chafery in Blès's painting, as will be shown in a subsequent chapter dealing with the forge. In front of the finery hearth in which the sow is melted down again, the finer is working with a long iron bar called a ringer (from French 'ringard') with which he keeps the molten iron in motion by stirring, an essential stage in the process of refining. The upper part of the front aperture is closed by a kind of shield made either of mortar or of hard wood, and resting on an iron bar called a morris bar (from French 'marastre'). This shield prevented the sharpness of the finer's vision being impeded by the glare of the fire.\(^3\) After the iron had been sufficiently refined, it would have been taken out of the finery and placed upon an anvil on which it was consolidated by the power hammer—depicted between finery and chafery—and shaped into an elongated bar which was the final size desired for forge products of malleable iron made ready for sale. In between the various ham-

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\(^1\) Applied alternately at Waldron furnace in Sussex, BM, Add. MS 33,154 passim — For 'pig' and 'sow' see Straker, pp. xiv, 82; cf. also App. XIV.

\(^2\) In 1592 a balance for the newly erected ironworks at Robertsbridge in Sussex was bought at London and shipped to Hastings, Pe., No. 372. In 1578 a balance for Rievaulx furnace, in Yorkshire, was bought at York from a merchant who had imported it from Flanders, Be., No. 527.

\(^3\) It is described by Swedenborg (p. 133) as a characteristic by which the type of finery introduced into Sweden from the Walloon country differed from the type introduced from Germany.
merings, the iron was reheated in the hearth of the chafery. There is a second anvil depicted in the front of the finery with two workers, one holding the iron, the other working it with a hand hammer. This implement served mainly for straightening and repairing the other implements employed at forge and furnace, and also for making new ones. As anvils and heads of the power hammer and other necessaries all of the heavy type were cast at the furnace, such an ironworks would have been practically self-supporting in respect of equipment.

INTRODUCTION OF THE NEW PROCESS IN ENGLAND

It is surprising that the direct method of producing malleable iron from its ores, conducted in the bloomeries, was replaced by a new process in a period in which bloomeries were functioning all over the British Isles in sufficient numbers to satisfy the local demand for iron in the rural districts. In addition, native production was supplemented by import of better-quality iron from abroad for the use of tool-making crafts in the cities and towns and for armament. It is all the more surprising in view of the fact that the erection of a bloomery required only a small outlay of capital, while a blast furnace and the tripartite establishment of the forge consisting of finery, chafery, and hammer were comparatively expensive structures. In addition, they had to be equipped with very much larger ponds and dams or bays for the storing of water, since the new process required a more effective motive power.

The advantage the blast furnace had over the bloomery by producing a quantity of iron which even at first was seven times as high within twenty-four hours and increased still more in the course of time,¹ was not a deciding factor in the period concerned. Between 1490 and 1500, when the blast furnace made its first appearance in Britain, and long afterwards, the use of iron was not so widespread in Britain and the demand not so urgent as to cause a production drive, which would have required the introduction of a new and more effective process. The reason has to be sought elsewhere. It clearly emerges from the nature of the products made at the first blast furnaces in England and their forges, and also from the demand they were intended to satisfy.

The first suggestion of the use of the indirect method comes from 1490, in which year the term ‘Irene founders’ occurred for the first time in English history.² (The term ‘founder’ was applied in the British iron industry long afterwards to the ironworker in charge of the blast furnace and the smelting operation.) The place was Buxted, in Sussex,

¹ See App. IV.
on the southern fringe of the ancient Forest of Ashdown. Here a furnace was definitely in operation from 1543 onwards which was celebrated for its gun-casting, and it therefore seems possible that the 'founders' employed iron from a blast furnace for casting in 1490. On the other hand, it is quite possible that they were casting shot (bullets). For this purpose any kind of iron, even such as was produced in a bloomsmithy, could be used by re-melting it in a small moveable hearth with the addition of various fluxes, such as antimony or tin, to facilitate liqutation.\(^1\) Thus the very brief reference to ironfounding at Buxted is much too vague to justify the conclusion that a blast furnace was in existence in this country in 1490. The first definite evidence comes about six years later.

In 1496, King Henry VII prepared to secure the northern border of England against a Scottish invasion.\(^2\) On the 13th December he commissioned one Henry Fyner to engage as many artificers, termed 'founders', and labourers as were wanted for the erection of buildings necessary for the manufacture of iron which was intended for use by the Royal artillery in the war with Scotland.\(^3\) Nine days later, on the 22nd, advance payments began to be made to the same Henry Fyner, who was a goldsmith of Southwark (London), for 'wrought iron', and on the 17th March 1497 for 'rough iron'. Both were produced at Newbridge in the Forest of Ashdown, which belonged to the Crown. The wrought or bar iron was forged by the 'great water hamor' and was worked into various appliances for binding wheels and stocks of gun-carriages. These were strakes, i.e. sections of wheel-rims, duelges, i.e., dowels or pegs for connecting the felloes of the wheels, and duledge-nails, bars for axle trees, bolts with forelocks, i.e. with wedges to keep the bolts in their places, cross-bars, and bolsters, i.e. transverse bars over the axles of the carriages. All this bar iron was worked for the King at Newbridge at a price of £4 6s. 8d. per ton, and was then carried at the King's expense to the Tower of London. The raw or pig iron sometimes termed 'rough iron fyned', was produced in a blast furnace and was subsequently submitted to refining in a finery hearth. This refined iron was bought by the King at £2 13s. 4d. per ton, and was delivered to Simon Ballard, one of the King's gunners at the Tower, who used it for casting gun shot at Newbridge. The shot varied in size and weight, ranging from 5 lb. each for 'serpentes', which were cannon of the smallest type, to 34 lb. each for 'demi-curtons', i.e. cannon of middle type, and to large bullets of 225 lb. each for 'bombardelles' or mortars. In addition, 200 small iron bullets were cast by him, each weighing a

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\(^1\) The method was known early in the fifteenth century according to a pirotechnia (Feuerwerkabuch), of 1454, O. Johannis, 'Eine Anleitung zum Eisenguss vom Jahre 1454', St E, 1910, pp. 1374-1375.

\(^2\) A. Conway, Henry VII's Relations with Scotland and Ireland, 1485-98, pp. 99 et seq.

\(^3\) PRO, Patent Rolls 12 Henry VII, membrane 29d.
Introduction of the Indirect Process

little less than 1\frac{3}{4} lb., apparently destined for hand-guns. The total weight of the 1100 bullets was 18 tons 44\frac{1}{4} cwts. 24 lb., and the cost of production £72 19s. 5d., of which £48 12s. 7d. was paid for the refined iron, 7d. for more iron supplied by Ballard, and £24 6s. 3d. for workmanship.\(^1\)

The various entries in the account of 1496–97 clearly show that a blast furnace and a forge were in existence at the end of 1496 on Crown property at Newbridge. This is the first English blast furnace of which there is definite evidence.

The entrepreneur of the ironworks was the above-mentioned Henry Fyner, who had apparently invested the capital necessary for stock and supplies. Evidently he was identical with the Harry Fyner, also referred to as a goldsmith, of Southwark, against whom a complaint was lodged by 'Pieter Roberdes otherwise called Graunt Pierre, yerne fonder dwellynge in Hertfelde (Hartfield) in the Forest of Ashdowne'.\(^2\)

The complaint is not dated, but is sometimes wrongly ascribed to 1493. The approximate date, however, is between 1493 and 1500. Graunt Pierre also was a gunner at the Tower and was mentioned as such on 16th May and 6th June 1497. A few months earlier (6th January) he received a reward of £1, on which occasion he was termed a ‘founder’.\(^3\) In his complaint, Graunt Pierre stated that he had been arrested and laid in chains on an action brought against him by Fyner on account of an alleged debt. It is most unlikely that this would happen to a gunner in the Royal service, or that the imprisoned man would have been accepted into this service after his release. For this reason, the action appears to have taken place no earlier than the latter part of the year 1497, or possibly even later. Graunt Pierre further stated that he had worked an iron-mill that was Crown property situated in the Forest of Ashdown, first alone from Christmas for nine months, and then jointly with Fyner for a period of the same length. The iron produced by him was delivered to Fyner at £3 per ton. The only furnace on record at that time as belonging to the Crown, was at Newbridge in the parish of Hartfield. At Hartfield itself there was only a forge, first referred to in 1496 as the property of Thomas Wildgoose of Hartfield and worked by John Stile.\(^4\) The rent paid by Graunt Pierre during the one and a half years of his tenancy was £20 per year, which is exactly the same as that paid by Pauncelett Symart from Michaelmas 1498 onwards for the ironworks at Newbridge.\(^5\) By all this evidence, it

\(^1\) Account of 1496–97, PRO, Exchequer Treasury of the Receipt, Miscellaneous Books, vol. 8, passim (supplying the evidence for the subsequent part relating to Newbridge, apart from the evidence quoted in footnotes).

\(^2\) PRO, Chancery Proceedings, Bundle 222, No. 12.

\(^3\) Excerpta Historica, p. 110. London, 1631.

\(^4\) Straker, p. 245 — John Stile is also referred to as carrying iron from Hartfield to the Tower on 1st June 1497, Account of 1496–97, loc. cit. p. 145.

\(^5\) PRO, Dukes of Lancaster, Ministers' Accounts, Bundle 454, No. 7329.
may safely be concluded that Graunt Pierre's iron mill was identical with the ironworks at Newbridge, that he had rented it from Christmas 1496 to Midsummer 1498, and that after the short interval of Pierre's imprisonment Pauncelett Symart became the new tenant.

The furnace at Newbridge is distinguished as the place where in 1509 guns of cast iron were successfully manufactured for the first time in English history by the above-mentioned Pauncelett Symart. The three iron guns cast by him were delivered to the Clerk of the Royal Navy at Portsmouth for the armament of the battleship 'Le Souvereign'.

In the last year of Pauncelett Symart's tenancy the iron mills were apparently in a bad state of repair, as a commission was appointed to examine whether the buildings were 'tenantlike'. Symart was constantly in arrears with his rent from 1498 and it took thirty years for his debt to be paid off completely. Apparently the rent was too high for profitable working. When Humphrey Walcott took over from Symart in 1512 the rent was lowered to £14 13s. 4d. per year. He was the King's 'gunfounder' and made iron bullets for new copper guns in the same year.

The products of the first blast furnace at Newbridge, so far as their nature and the quantity produced are known, were sent to the Royal Arsenal in the Tower of London to be used by the artillery. The idea was to obtain new and improved weapons of war by producing them from iron liquefied in a blast furnace. One of the new weapons hitherto not used in England was the cast-iron bullet, which was far superior to the bullets usually made of stone or wrought iron in those days. Another, which was far more difficult to produce than the bullet, was the cast-iron cannon. This was not so expensive to make as the usual cannon cast from bronze or brass or produced from wrought-iron bars by a tedious process of hammering and welding. The cannon, though already known for a considerable time in Europe, was not yet universally accepted as a war weapon at this date. As late as 1500 old primitive weapons such as catapults and arrows had not yet disappeared completely. Even the celebrated artist and engineer Leonardo da Vinci applied himself to the improvement of the catapult.

Cannon-balls or bullets of cast iron had been produced on the Continent, but not in England. They had a considerable advantage over cannon-balls of stone or wrought-iron balls termed 'dices'. A cast-iron cannon-ball had a much smaller diameter than a stone ball of the same weight. This rendered it possible to make the chase of the gun stronger and longer without increasing the weight. Accordingly, a greater charge of powder could be employed, whereby the propelling force of the gun was increased. Further, iron bullets cast in moulds were more even on

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1 App. VI.
2 PRO, Book of Commissions, No. 95, fol. 11, and Duchy of Lancaster, Ministers' Accounts, Bundle 454, Nos. 7299-7344.
3 Ibid., No. 7302, and Exchequer QR, Bundle 53, No. 29.
4 W. B. Parsons, Engineers and Engineering in the Renaissance, p. 44. Baltimore, 1939.
the surface and more symmetrical than stone balls and iron dices, both of which had to be shaped by hand with chisel and hammer. Last but not least, the production of cast-iron balls was very much less expensive.1 Iron cannon made in England during the fifteenth century are on record, but the kind of iron used in their manufacture is not mentioned.2 Probably they were of wrought iron. Two early specimens of the mortar type were found in Sussex, the Bodiam Castle mortar, now at Woolwich, and the Eridge gun. They were of wrought iron, with parts of cast iron. Neither of these mortars is dated, nor are their places of origin really known; they are named after the places where they were found.3

The English army had already experienced the disastrous effects of an adequately equipped artillery. In the war of 1449–50 the French artillery organised by the brothers Bureau, the great gunners of Charles VII of France, had destroyed sixty castles within four days and blasted the English out of their French possessions. Towards the end of the century French cannon had acquired a high international repute because of their splendid quality, the rapidity of firing, and their use of cast-iron shot instead of stone balls.4

King Henry VII well understood the importance of artillery. He increased the number of his gunners more and more. In 1489 they numbered 30; in 1497 there were 49 gunners at the Tower. Many of these men were of foreign origin, some from the Low Countries (Antwerp, Geldern, Harlem), and from Spain, while the majority had French names like Ballard and Grand Pierre, who worked at Newbridge. These gunners were not only artillermen but also experts in shot and gun founding, which makes it very probable that the art of casting iron bullets and guns was introduced from France. Pauincelett Symart also appears to have been a Frenchman, as another Symart with the first name of Lambert worked with him at least in the last years of the former’s tenancy at Newbridge. Lambert Symart had come from Normandy in 1494.5

EARLY DEVELOPMENTS IN THE WEALED OF SUSSEX

In addition to Newbridge several ironworks were installed in Ashdown Forest and its immediate vicinity. In 1511 Robert Scorcer, a gunner of the Tower and a shot-founder, supplied iron bullets for the battleship

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1 The iron balls cast by Simon Ballard at Newbridge in 1497 cost 3s. 4d. per cwt., while iron dices wrought by the smith Cornelis at the same date cost 1s. 4d. a cwt., PRO, Exchequer Treasury of the Receipt, Miscellaneous Books, vol. 8, pp. 34, 61, 92.
5 Lambert was co-partner in 1511 and 1512, PRO, Duchy of Lancaster, Book of Commissions temp. Henry VII, fols. 11, 26. In 1511 he made forty carts for the Arsenal at the Tower, PRO, Exchequer QR, Bundle 55, No. 29. Apparently he was the hammerman, while the other Symart was in charge of the furnace.
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'Mary and John', and in the following year more 'iron shot' to the total amount of ten tons for the guns of the Royal Navy. Scorcer was the lessee of Parrock forge in the parish of Hartfield. Before he died in 1514 he appears to have worked up a not inconsiderable trade in iron bullets, for in his will of 1513 'gunstones of iron' are referred to which were dispatched to London and to several unspecified places in Sussex. All these bullets were in addition to those which remained at Parrock in the Parish of Hartfield, where he worked. Parrock is called a forge in the will, but it is very probable that there was also a furnace, since in 1518 a furnace, a finery, and a hammer (which generally included a chafery) at Parrock is referred to as the property of Richard Warner.¹

![Map VI. Early development in Sussex (1490–1543).](image)

Apart from Newbridge and Parrock, iron was produced for arms-making at other places which were mainly in Ashdown Forest, although not all of them can be located. In 1509 Claudius Robinson erected a steel forge quite near Newbridge. Suppliers of iron gunstones in 1511 were Clays Harms and Richard Sackfield, both referred to as gunstone makers. Harms worked in the Forest of Ashdown making bullets of wrought iron for the Navy to a total amount of 335. Where Sackfield worked is not known. A third was John Bowyer of Hartfield, who in 1513 supplied not only gunstones but also 'dyes of iron', i.e. wrought-iron bullets.² By the names, to which those of the previously-mentioned Scorcer and Walker should be added, one noticeable difference from


² PRO, Echingham QR, Bundle 55, No. 29, fol. 8r – L & P, Vol. 11, Part 11, p. 1452. London, 1864 – Straker, p. 245. For the steel forge see App. VI.
earlier times is shown. There are more ironworkers with English instead of French names, so that it is possible to think of the development which had taken place in the meantime in terms of a growing home industry.

In the same period iron cannon also were made. In 1512 the citizens of Great Yarmouth were advised to have made for their use four iron bombards each with two iron chambers, but there is no evidence to show whether they were of wrought or of cast iron. In the following year two guns, definitely of cast iron, were paid for at Greenwich. Their total weight was 1862 lb., and their maker was Reignold Roberts but his works is not mentioned. He may have been a descendant of the above-mentioned ironfounder Pieter Roberdes called Grand Pierre, of Newbridge.1

Between 1521 and 1540, in addition to Ashdown Forest, further districts of iron-working in Sussex can be ascertained from documentary sources, in the north-east and south-east of the county.

There was a forge at Bayham on the border of Kent but just within the parish of Frant in Sussex; it stood on the property of the Premonstratensian Abbey of Bayham. According to a rental of the Abbey the tenant was William Wybarne in 1525. The high rent of £3 a year indicates that the forge was more than one of the ordinary bloomeries. In 1544, Frenchmen were working for Wybarne, of whom one, Holmes Gilham, had come from Normandy in 1538, and was buried at Frant in 1559. William Wybarne of Bayham was a wealthy landowner, who in 1525 acquired the manor of Halkwell and in 1545 the lordship of Pembury, both in Kent and not far from Bayham.2

Brookland forge, also in the parish of Frant but almost on the border of Wadhurst parish, was in operation early in 1521, at which date John Barham, an ‘Iron man’, bought it. In 1544 Frenchmen from Normandy were employed by him, one of whom had come to England in 1537; he was buried at Frant in 1558.3

Originally these forges may have been bloomeries producing their iron directly from the ore, but their employment of French workers suggests a change to the indirect method; yet if so there would have been furnaces in the vicinity of the forges, and there is no direct evidence of a furnace anywhere near them at such a date. In the adjacent parish of Rotherfield, Frenchmen were living very early, in any case during and after 1538, when the parish registers commence. There were seven different French families living in the parish between 1538 and 1542. The lord of the manor of Rotherfield was Lord Abergavenny, whose residence was in Eridge park on the border of the two parishes of

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Rotherfield and Frant. There is definite evidence that he had a furnace operating in 1562 west of Eridge and within the parish. Among the Frenchmen in the parish three were ironworkers employed later at other works in Sussex. One was Isambert Pynyon, one of three members of a French family living at Rotherfield (the first Pynyon came to England in 1510). He worked at Buxted in 1544, but married at Rother- field, three years later. Another was Anthony Morys who married at Rotherfield in 1542 but later also worked at Buxted. A third was Leonard Callis, whose name may indicate his origin from Calais. He lived in the parish from 1541 to 1543 in which years two of his children were baptised there. From 1548–49 he was a finer at Robertsbridge forge, but seems to have returned, since he was buried in Frant in 1596. As these ironworkers lived in Rotherfield parish before they left for other places, it may safely be concluded that their first place of work was Lord Abergavenny's furnace and forge west of Eridge which, therefore, were probably in operation in 1538 or even earlier.¹

Between 1530 and 1540 the iron industry of Sussex extended still further. West of Newbridge a new furnace was erected in 1534 on Crown property at a place called Stumlet or Stimulet in the Forest of Ashdown. The first lessee was John Levett of Little Horsted, brother to William Levett, parson of Buxted, who later played a very important part in the English iron industry.

The first evidence of blast furnaces in the south-eastern part of Sussex belongs to about the same time. In 1535 Socknersh furnace in the parish of Brightling is referred to as the property of John Collins of Burwash. A furnace on the little river Limden in Darfold wood with a forge at Etchingham was demised in May 1539 to Thomas Welsh or Walsh by the owner Thomas Oxenbridge who had much property in the surrounding district.² Two years later a furnace and a forge were erected at Robertsbridge on land of the former Cistercian Abbey, which was granted to Sir William Sidney in 1540. A second furnace owned by Sidney was built at Panningridge in 1542. About the same time another furnace was established at Pasley in the parish of Ticehurst. It is first mentioned in 1543, when Sir James Boleyn, the uncle of the unfortunate Anne Boleyn, sold Pasley including 'one furnace' to Thomas May and his son Thomas. Thomas, the father, however, appears to have had the lease of the property before he purchased it.

In 1544 three Frenchmen, all born in Normandy, were working for the Mays. One of them had been in England for twenty, another for seven, years at this date. The younger Thomas and his brother John were gunfounders who cast a bronze gun for Queen Mary in 1554.

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Both were appointed as gunners in the Tower, John since 1549 and Thomas since 1555.¹

It is remarkable that two furnaces should have been built by the same owner almost within the space of one year. These were Robertsbridge (1541) and Panningridge (1542), both of which produced pig iron for the same forge at Robertsbridge. Panningridge furnace was probably built because of the discovery of superior ores near by. Near Panningbridge some of the best ores in Sussex were available.² This would account for the installation of a third furnace which after 1549 was installed between Panningridge and Ashburnham by the Ashburnhams, who about twenty years later acquired Panningridge furnace in addition to their furnace near Ashburnham, which ensured their complete control over the mineral resources of the district. This also explains the long survival of Ashburnham furnace which was the last in south-east England when it closed down in 1812.

The extension of ironworking to the south-east of Sussex made it possible to take advantage of water transport instead of the much more expensive transport by road, on which the earlier works in Ashdown and Waterdown Forests had to rely exclusively. Robertsbridge forge, which consumed the pig iron produced at Robertsbridge and Panningridge furnaces, had shipped iron by the river Rother from Bodiam bridge since 1542, and from 1553 onwards in smaller barges from Udiam bridge, which was still nearer to the works. At the harbour of Rye the iron was trans-shipped to seagoing vessels which carried it mainly to the market of London. Etchingham forge, supplied with pig iron from Darfold furnace, also used the river Rother to Rye harbour. The difference in expense between water and road transport was considerable. From a statement made at Rye in 1635 it emerges that the iron sent from Robertsbridge and Etchingham, and from Hawkhurst would have cost £100 a year more if sent by road instead of being shipped on the Rother.³

The creation of a new working-area in the south-east indicates progress around 1540, which progress was of two kinds: technical and economical. Firstly, ores of better quality were sought, and secondly, the advantage of a geographical position nearer to the coast began to be exploited.


² Ashburnham ore, mined near Panningridge, contained 42-08% ferric oxide, i.e. 37-49% of metallic iron, which compares favourably with ore mined farther north, near Wadhurst, giving but 30-66% of metallic iron. The percentage of silica is 6-45% at Ashburnham, but very much higher (26-10%) near Wadhurst, a great disadvantage. F. H. Edmond, Geological Survey of Britain: The Wealden District, pp. 23-24, 30, 89. Second edition. London, 1948. Ashburnham ore was bought for Panningridge furnace at the time of its erection in 1542, Pe., No. 373, Straker, p. 366.

³ Straker, pp. 189, 312. The figure of £100 is equivalent to the price of 6½ tons of bar iron wrought in Sussex in 1636, Sussex AG, vol. XLIII, p. 14.
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Despite a certain progress which though limited is unmistakable, the total number of blast furnaces was not more than six by 1539, with three more by the end of 1542. Considering the fact that about half a century had elapsed since the first introduction of the indirect method, the progress seems very slow. There is a possibility that the old direct method, which was still the only one employed in all the other parts of Britain, also survived in Sussex for a time, though there is no conclusive evidence that it really did. Even this would not suffice to explain the slow progress, nor was a shortage of wood responsible. A belt of woodland, which included the ancient Forests of Ashdown and Waterdown, with splendid oaks, extended right across the northern part of Sussex. On the property of dissolved monasteries, such as Robertsbridge, ample wood resources were also available. It will be shown in subsequent chapters that certain deficiencies in the method of producing a pig iron completely appropriate for casting as well as for conversion into malleable iron impeded the development and expansion of iron-production in blast furnaces and forges in the early period.

Another reason, probably connected with the inferior quality of the iron produced, was a different direction taken by the armament industry. Henry VII had created a home industry with the help of French founders and gunners. His son, Henry VIII, however, placed large orders for arms in foreign countries, especially the Low Countries. He also induced alien gun-founders to settle in London. Most of the cannon cast abroad and all those cast in the London foundries were made of non-ferrous metal. The making of iron guns for ordnance had been in the hands of the King's master smith, Cornelius Johnson, an alien from the Dominions of the German Emperor, but only guns of wrought iron were made under his supervision. The bars of the guns were welded together, and then surrounded with circles of wrought iron, a method already practised in the late Middle Ages. It was a rather elaborate and costly operation.¹

A turning-point which initiated a new expansion of the iron industry in Sussex came in 1542. It was again the Crown which acted as the driving force, just as it had done half a century earlier and for the same reasons. Again it was the necessity of increasing the production of war weapons at a time of national danger. In 1496 it had been the threat to the north of England from the Scots. In 1542 the danger was greater, since a war with France was imminent, which meant that the most populous part of the country, including London—both capital and chief centre of commerce—was exposed to invasion. The situation required immediate defensive measures by fortifying the south coast. Owing to the development of artillery coastal defence against enemy attacks from

the sea had increased in importance. The greatest change in the employment of artillery took place in the later years of Henry VIII's reign. This was the placing of guns in forts at vulnerable points on the seaboard facing France.¹ As a large number of guns was required for the defence of a long coastline, recourse was taken to cast-iron guns, since they were less expensive than those of bronze or wrought iron.

It was very fortunate for the King and his country in such precarious times that iron-founding had not ceased completely in Ashdown Forest. From 1534 to 1539 Simon Forneres from Bruges in Belgium, who was the 'King's gunstone maker', employed first in this capacity in 1529, was the sub-tenant of the ironworks at Newbridge.² He may have died in 1539 or shortly afterwards, for his office of royal gunstone maker was transferred in 1541 to William Levett, rector of the parish of Buxted, who held it until his death in 1554. It seems an odd post for a parson; Levett, however, was not inexperienced in the iron trade. From 1533 to 1534 he was a deputy for the receiver of the King's revenues in Sussex, including those from Newbridge ironworks. In this capacity he appears to have acted as executor for his brother John, who was tenant of Stumlet furnace and the steel forge in Ashdown Forest until he died in 1535.³ Though not an ironmaster, Parson William evidently had good insight into the business of administering ironworks. Considering his antecedents, it is not surprising that Levett should have been chosen by Henry VIII to administer the founding of cast-iron guns and shot on a larger scale than ever before.

The great occasion of the casting of guns under Levett's supervision, frequently mentioned by English historians from the late sixteenth century onwards, took place in 1543.

The site of the furnace is not absolutely sure, but there is sufficient evidence to justify the assumption that it was at a place a little north of Oldlands Hall, on the extreme border, but just within the parish of Buxted. Oldlands and an adjacent 'parcell of land' called 'Synderfelde', a place-name which indicates the dumping of slags, belonged to Levett.⁴

The casting of iron guns was a complete success, made possible by the combined efforts of some of the best experts available in the country. Levett had secured the services of the largest number of Frenchmen employed in any of the Sussex ironworks at the time, two of whom had previously been at Rotherfield, probably working at Eridge. From London, the King had sent an expert founder of bronze guns, Peter

² PRO, Duchy of Lancaster, Ministers' Accounts, Bundle 446, Nos. 7169 and 7170, Bundle 456, No. 7352 — Page, p. 94.

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Baude, also of French origin, who worked at Houndsditch, London, which was one of the principal English gun-foundries.\(^1\) Despite the value of his experience in metal founding, success could not be achieved without the knowledge and skill of an ironmaster who knew how to operate a furnace and was able to furnish the liquid iron for casting. This was Ralph Hogge, an Englishman to judge by his name, although remarkably little is known about him before 1543.

After the successful event Baude returned to London, but Hogge remained at Buxted in Parson Levett’s service. He married in Maresfield in 1560 and built a house between Buxted and Maresfield, which is adorned with a cast-iron slab with the figure of a hog and the date 1581, still to be seen on the outside of the house. Hogge continued to produce iron, first at Buxted (Oldlands) and later also at a second furnace called Marshalls situated in the adjacent parish of Maresfield. Though mainly concerned with the production of cast-iron guns and shot, he also produced pig iron at his furnaces and bar iron at the forges.\(^2\)

By the success of 1543 Buxted won the status of a model ironworks, the influence of which radiated to other works in Sussex, such as Panningridge and Robertsbridge. Charles Pulleyn, founder at Buxted, was frequently called in between 1546 and 1549 whenever trouble arose in the working of the furnace. He occasionally laid the hearth, dressed the bellows, and even controlled the blowing of Panningridge furnace at the initial stage of a campaign. In 1548 he was asked for a suitable firer for Robertsbridge forge and he engaged a man from the forge at Sheffield in Sussex. In the following year, in which considerable repairs were made at Panningridge, Charles came from Buxted and repaired the walls of the furnace. It is possible that at some later date he was employed at the furnace of Ashburnham erected around 1550, since an unmarried daughter of his was buried at Ashburnham in 1563. His employment would fall into a period in which Robertsbridge forge was receiving large consignments of pig iron from Ashburnham furnace, since the furnace near Robertsbridge was not yet working again. Pulleyn may have been ‘Mr. Ashburnham’s founder’ referred to in a document of 1556.\(^3\)

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1 Foulkes, loc. cit., pp. 45, 117.
2 According to a statement made by George Kenyon of Fletching who had worked for Hogge from about 1573 to 1581, PRO, Chanery Proceedings, Eliz. K.3, No. 31. Pig iron was produced quite early at Buxted, since Levett bequeathed to Hogge, his servant, 6 tons of ‘sowes’ in his will of 1554, Straker, p. 147.
3 E. Straker, Westall’s Book of Panningridge, Sussex AC, vol. lxxxii, pp. 225-226 — Pe., Nos. 372A (2, 3, 5), 375, 383 (1 and 2) — Charles was a Frenchman, he married at Maresfield in 1550 (Parish Registers: Charolus Pullen gallus); see also Ashburnham Parish Registers. Another Frenchman, James Morell, worked at Wm. Levett’s ironworks in 1544, when he was made a denizen, later he was employed at the hammer at Ardingly in Sussex (1583, Ardingly Parish Register).
CHAPTER XI

EXPANSION OVER THE BRITISH ISLES

THE BOOM IN THE WEALD

The casting of iron guns at Buxted in 1543, promoted by the Crown and accomplished by the combined efforts of the best experts in founding, stimulated the further expansion of the indirect method of iron-making. The immediate result was the creation of new ironworks in Sussex. According to the available documentary evidence eleven new blast furnaces were built between 1543 and 1548, and perhaps one more (Ashburnham), the earliest date of which, however, is uncertain. (The furnace at Robertsbridge, which had been one of the older furnaces, was discontinued in 1547 and not rebuilt before 1573.) Anyhow, in these five to six years more furnaces were erected than within the fifty years prior to 1543, so that by 1548 a total of twenty or even twenty-one blast furnaces were in existence. At the same date the maximum number of forges, as the evidence shows, was twenty-eight. This makes a total of forty-eight or forty-nine works, which is consistent with a return made at the end of 1548 giving the total of all the ironworks in Sussex at fifty-three.¹

Production kept pace with the increase in the number of ironworks, and Sussex ironmongers began to export into other parts of England. In the Custom Accounts of 1550 iron figures for the first time among the exports from Sussex. It was shipped to Jersey, Dartmouth, Southampton, Chichester, Sandhurst, London, and Colchester.² The rapid expansion was bound to have repercussions. There was a public outcry against excessive consumption of wood by the ironworks, which inspired the enquiry from which the above figures are taken, and this resulted in a temporary decline and the closing down of some of the

¹ HMC, MSS of the Marquis of Salisbury, vol. xiii, p. 23. London, 1915 — Straker, p. 119 and passim (for number of forges) — Rhys Jenkins, NHER. Tr., vol. i, p. 20, supposed that of the fifty-three works twenty-six were furnaces. Cf. also the list of furnaces in App. V.
works, e.g. Robertsbridge, Newbridge, Steel Forge. The decline, however, did not last long. The demand for iron in England was too great for that. Public awareness of the situation is reflected in a pamphlet written in 1549 in the form of a dialogue. The anonymous author estimated the output of iron in England at less than half the amount required for internal consumption. He also drew attention to the inevitable consequence: dependence upon supplementary imports from abroad, which not only weakened the prosperity of the country, but also imperilled its safety in the case of war. He pointed out that the King was compelled to purchase from abroad all sorts of equipment for army and navy, such as ‘armour, all kind of artillerie, anckers . . ., yron, steile (i.e. steel), handgonnes, and manie other things’, which had to be paid for ‘at the price the strainger will set’.

The effect of the complaints about excessive wood consumption by the growing iron industry in Sussex was that after 1550 the industry began to extend across the borders of the county into the adjacent parts of Kent and Surrey, which provided untouched wood resources. Neither the complaints about depletion of forests nor the restrictive measures repeatedly imposed by legislation were able to delay the process of expansion. The growing demand for iron combined with the desire to make England more independent of foreign imports stimulated the growth of the iron industry in the Weald so that after 1550 and still more after 1560 a number of new furnaces and forges were set up there.

The fear of guns cast in the Weald being exported illegally to England's enemies, the most dangerous of which was Spain in the sixteenth century, induced the English government to order an enquiry regarding the number and character of the nation's furnaces and forges. This was conducted by an Admiralty official, one Christopher Baker. The lists Baker submitted constituted a detailed survey recording a total of one hundred and seven ironworks of which forty-nine were furnaces and fifty-eight forges. Actually the lists are not completely comprehensive, since fifty-one furnaces can be derived from documentary evidence. In 1574 the Wealden industry held an unrivalled position in the country, since there were only seven furnaces outside the Weald, four in South Wales and Monmouthshire and three in the Midlands. Its supremacy

1 Straker, pp. 249-250 (erroneously dated to 1539), 311.
3 For the following compare the list of English furnaces in App. V, which is as comprehensive as possible considering the present state of historical research. There are, however, a few additional furnaces of which no records exist, such as Tollesly, parish of Frant, Sussex, which, judging by the large bay and the great quantity of slag left, must have been a considerable one, Straker, p. 268.
Expansion over the British Isles

continued for at least half a century, at the end of which more than half the blast furnaces in England and Wales were still situated in the Weald.\(^1\) The more that the number of blast furnaces increased in other regions, the more it decreased in the Wealden area; first slowly, but rapidly from about 1660 onwards, as is shown in the following schedule representing the regional distribution from 1574 to the end of the charcoal iron era (based on App. V).

<table>
<thead>
<tr>
<th>District</th>
<th>around 1574</th>
<th>1630</th>
<th>1640</th>
<th>1653</th>
<th>1664</th>
<th>1717</th>
<th>1790</th>
</tr>
</thead>
<tbody>
<tr>
<td>South-east</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hampshire</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Weald</td>
<td>51</td>
<td>49</td>
<td>39</td>
<td>36</td>
<td>29</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>South-west of England</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and South Wales</td>
<td>4</td>
<td>14</td>
<td>18</td>
<td>14</td>
<td>14</td>
<td>16</td>
<td>11</td>
</tr>
<tr>
<td>Midlands</td>
<td>3</td>
<td>11</td>
<td>12</td>
<td>9</td>
<td>10</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>Chester and North Wales</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Sheffield area and north-east</td>
<td>0</td>
<td>8</td>
<td>6</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>North-west</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>58</strong></td>
<td><strong>85</strong></td>
<td><strong>78</strong></td>
<td><strong>73</strong></td>
<td><strong>68</strong></td>
<td><strong>61</strong></td>
<td><strong>24</strong></td>
</tr>
</tbody>
</table>

The proportion of forges to furnaces was on the average five to four between 1574 and 1653.\(^2\) It is lower than in the other parts of the country, which is partly explained by the considerable number of Wealden furnaces mainly producing castings, for which work at the forge was not required.

EXPANSION INTO SOUTH WALES AND MONMOUTHSHIRE

Up to 1560 the indirect process was completely confined to Sussex and the adjacent districts of Kent and Surrey. In all the other counties the direct method conducted in bloomsmithies was still being employed exclusively.\(^3\)

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\(^1\) J. Norden, *The Surveyors’ Dialogue*, pp. 214–215, London, 1607, estimated the total number of ironworks in Sussex alone at ‘neare 140’ which, however, is based on hearsay evidence (‘I have heard, there are, or lately were’) and certainly this figure is too high (Rhys Jenkins, in *Neue Tr.*, vol. 1, p. 24) — In an undated petition the number of ironworks in the Weald in 1653 given as seventy-three (thirty-three furnaces and forty forges) was said to represent ‘half the number of Ironworks within the Kingdom of England’, Sussex AC, vol. xxxii, p. 24.

\(^2\) According to statements about ironworks made in those years, *Sussex Notes and Queries*, vol. vii, pp. 98–103; Sussex AC, vol. xxxii, pp. 21–22.

\(^3\) See above Chapter 9.
Expansion over the British Isles

Iron-making by the indirect method commenced in South Wales and adjacent Monmouthshire around 1564, in which year the Taff furnace between Cardiff and Castle Goch is first referred to. Soon afterwards another furnace was installed at Dyffryn in the valley of the Afon Cynon in Glamorganshire. One of the forges was in the same valley, near Mountain Ash, the other at Llanwonno. The evidence of four more furnaces operated in Glamorgan in the sixteenth century is of a much later date than 1564. One isolated furnace was built in the Manor of Coity Anglia, north-west of Bridgend, in 1589. Three furnaces were in the Taff valley. One was at Pontyryn, which is now a part of Aber-canaid, with a forge on the opposite side of the river Taff, but lower down the valley. Evidence for the existence of this furnace, however, is based merely on the discovery of early firebacks at the locality. The furnace at Pentyrch, north-west of Cardiff, belonged to the Mathews of Radyr, an important south Glamorgan family. This furnace at which guns were being cast shortly after 1600, was strongly

1 For the following, see above Map VII, and App. V. The forge attached to the Taff furnace apparently was at Rhyd-y-Gwern in the Glamorgan part of the parish of Machen, see below p. 298.

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suspected of being a source of illegal traffic in arms. The first evidence about it is from 1600, at which date it was described as 'the old furnace', which suggests that it had been in use for some time, and also that a second furnace was operating in the district.

While the impulse to introduce blast furnaces in Glamorgan first came from Sussex (Taff and Dyffryn furnaces and, perhaps, Pontyryn), the rise of the industry in adjacent Monmouthshire was mainly due to a Worcestershire man. Extensive iron-working commenced in Monmouthshire a few years later than in Glamorgan, the centre being Pontypool and its immediate vicinity with three furnaces and their forges: Cwmfrwdoer (later also called Pontypool furnace and mentioned first in 1570), Trosnant, and Pontymoel both erected six years later. The Cwmfrwdoer and Trosnant furnaces belonged to Richard Hanbury, originally of Worcestershire and afterwards a goldsmith in London. In 1570 Hanbury became partner in a lease of the Tintern wireworks granted by the Company of the Mineral and Battery Works in London, and subsequently acquired the Company's ironworks in which the special Osmond iron required for wire drawing was produced. One of them was at Monkswood, north-west of Usk, first referred to in 1565. In 1576, when Hanbury had acquired the large tracts of woodland between the rivers Ebbw and Usk, including the iron mines from the Earl of Pembroke, he built Trosnant furnace.1 In the same year Pontymoel furnace was erected by John Truve (or True). Apparently he was either identical with, or a descendant of, a Sussex founder of the same name who had been the first iron-founder at Robertsbridge furnace from 1541 to 1544.2 As far as can be ascertained from documentary sources, Truve of Robertsbridge was the only founder not of foreign origin among the many French founders employed in the early iron industry of the Weald.

In addition to the woodlands between Ebbw and Usk, Hanbury took possession of almost all the woods within ten miles from Tintern, and of the best mines in Monmouthshire for the making of Osmond iron.3 The control of such vast resources of fuel and ore gave him an unrivalled position, and enabled him from 1580 onwards to operate four furnaces with their forges (Abercarn, Cwmfrwdoer, Monkswood, and Trosnant). His dominant position, however, was based to some extent on fraud. He not only used the ores and woods claimed by the Company for the maintenance of their wireworks, and produced iron which he sold for his own profit, he also neglected the delivery of Osmond iron to Tintern which he was bound to make from his ore and wood. As a result he became involved in several lawsuits by which the Company enforced the fulfilment of the obligation.4

1 CRO, Newport, JCH, 1560. 2 PC, Nos. 371, 372, 377(2), 379(2).
3 BM, Landowne MS 75, fol. 200.
4 PRO, Exchequer, Special Commission, No. 1518, Depositions by Commission, 39 Eliz., Hilary 23.
Expansion over the British Isles

Apart from the ironworks concentrated in the Pontypool area, there were some isolated furnaces farther away: at Abercarn and Bedwellty in the south-west, and Clydach in the north-east. The furnace near Abercarn was a foundation of Edmund Roberts of Hawkhurst in Kent. Though no ironmaster himself, he made a fortune in the iron industry, and then lost it.¹ The furnace near Abercarn was erected by him in 1576, after he had been granted woods and minerals jointly with Hanbury by the Earl of Pembroke. Three years later he died in debt and the works subsequently came into the possession of Hanbury. The furnace at Bedwellty is mentioned only in 1597. It may have been a late and short-lived attempt, made by two merchants of London and of Bristol respectively for whom it was worked, to invest capital and to share in the profits of the regional iron industry, which however by that time was already on the decline. The early evidence, relating to the Clydach furnace in the parish of Llanelly in Breconshire, is not very reliable. It is supposed to have been built first in 1590. After several translocations and rebuildings it survived until the early nineteenth century.

Clydach and Trosnant furnaces continued working in the seventeenth and eighteenth centuries. The Taff furnace was replaced in 1680 by a new furnace west of Caerphilly which remained in operation throughout the eighteenth century. A great number of ironworks however did not survive. The short duration of the production drive in the second half of the sixteenth century was caused partly by the rapid deforestation through excessive consumption of wood for charcoal. It was aggravated by an apparently complete failure to replenish the natural supply of wood by the planting of coppices. The destruction of woods was the subject of complaints made by Rice Merrick who in 1578 wrote about the many forests and woods in Glamorgan as something already belonging to the past, since many of them by 'the Iron Milles, were spoyled and consumed'.² In Monmouthshire it was above all Richard Hanbury who spoiled the woods, to such a degree that in 1578 legal proceedings were taken against him on behalf of the Crown because of his 'lamentable spoyle of most goodly tymber trees' growing in the valley of the river Usk. As a precaution against the indignation aroused by his spoliations in the adjacent villages Hanbury demised several of his ironworks temporarily, so that for a time he could stay away from Monmouthshire, because the 'ill will and malice' of the population made him fear for his life.³

There were however other reasons for the decline which set in after 1600 in this area. During the preceding production drive, a considerable

² A Books of Glamorganshire's Antiquities, by Rice Merrick (1578), edited by J. A. Corbett, p. 112.
iron trade had been built up extending from Ireland to the Low Countries, and from Bristol to Birmingham. It started immediately after the erection of Sir Henry Sidney’s furnace in Glamorgan, whence ingots of steel were shipped to Sussex, and bar iron in 1565 to Bewdley, the great trading centre of the Midlands, and to Dublin in 1569–1570. As soon as Hanbury had firmly established his position in the iron production of Monmouthshire, he began in 1578 to send bar iron from Monkswood to Bristol, and from about 1589 regular monthly consignments to iron merchants in Bristol and Birmingham, and towards the end of the century export increased. The growing export of iron, however, which had largely contributed to the prosperity of the industry in Glamorgan and Monmouthshire was curtailed after 1600 by competitive production in districts in which iron-making had hitherto been conducted on a small scale in bloomeries, and the Bristol market was lost to the new iron industry of the Forest of Dean which in the seventeenth century became the main supplier. The Midlands became increasingly self-supporting with the increased activity in iron-production which set in between 1590 and 1600.

**THE MIDLANDS AND NORTH WALES**

In the Midlands blast furnace production commenced about the same time as in the south-west, but did not at first expand very rapidly. Before 1590 only a few isolated blast furnaces were erected by great landowners of the nobility desiring to utilise the wood resources of their extensive forests. The first furnace was established in the Chase of Cannock in Staffordshire, by William Lord Paget between 1561 and 1563, after a ten-years lease of a bloomsmithy built in 1542 at Risom bridge in the same district had expired. Between 1563 and 1576 the Earl of Leicester had an ironworks built in the vicinity of Cleobury Mortimer, in Shropshire, first with one and later with two blast furnaces. The works was supplied with charcoal from the extensive woodlands in Wyre Forest.

In the principal iron-working district of Shropshire, both sides of the river Severn with Coalbrookdale as centre, the bloomery process was still employed exclusively up to the middle of the sixteenth century.

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2. PRO, *Exchequer Depositions by Commission*, 20 Eliz., Easter No. 2; Bills and Answers 29/24.
4. Survey of Lord Paget’s possessions compiled in 1543–44, in the next survey of 1558–59 no ironworks are referred to, Stafford, Wm. Salt Library, D 1736.
North-west of this area, in the vicinity of Shifnal, a blast furnace was erected and a bloomsmithy at Lizard was converted into a forge with forgeries in 1564. Furnace and forge were built at the expense of the Earl of Shrewsbury, on his property.

The first blast furnace in south Staffordshire was built at West Bromwich between 1590 and 1597. In the vicinity four bloomsmithies were still in operation in 1597.\(^1\) Two further furnaces were built at Middleton, in Warwickshire, with a forge atHints, in Staffordshire, in 1591, and in the following year at Oakamoor, East of Stoke-on-Trent, in north Staffordshire. At Oakamoor a bloomsmithy had closed down only a few years earlier.\(^2\) About the same time a furnace was established near Stone between Stoke-on-Trent and Stafford. The date of its erection is not certain, but it was before 1600.

In the area west and south of Dudley in Staffordshire iron-production in bloomeries was continued still longer. West of Dudley three bloomsmithies were in being in 1585, one of which was termed the 'new' smithy and had apparently been set up not long before. A second called Funsloe Smithy was still busy in 1594.\(^3\) The first blast furnace in this


\(^2\) PRO, Chancery Proceedings, Eliz. W9, No. 21.

\(^3\) Dudley Papers, Box 3, Bundle 3; Box 19, Bundle 32 — PRO, Chancery Proceedings, Eliz. W15–19.
district was built about 1595 in Gornal wood between Dudley and Himley. South of Dudley there were bloomsmithies at Cradley and Halesowen. At Halesowen a blast furnace was substituted for the bloomer between 1602 and 1605.

In Cheshire and North Wales the indirect method was not introduced in the sixteenth century apart from one single case: in the township of Nanney, in Merionethshire, a furnace was erected in 1597 by John Smith of Newcastle-under-Lyme, in Staffordshire. In November 1596 he rented for twenty-one years an ironworks owned by Hugh Nanney and his son Griffith. Smith seems to have modernised the older ironworks by converting it into a blast furnace with forges, since the capital he borrowed was destined 'for the makinge . . . of forges, fornasces and other buildinge'. The necessary capital was supplied by Wm. Dale, a London grocer, and Wm. Grosvenor, a Shropshire man who in 1593 had set up forges and warehouses at West Chester for arms to be used in Ireland. It is possible that the furnace and forge at Nanney were built with the intention of supplying Grosvenor with iron. The enterprise, however, was of a very short duration and evidently not successful either, since legal proceedings in 1619 disclosed that Smith had made no profit and had ceased to work the furnace about fifteen years earlier.²

DERBYSHIRE, YORKSHIRE, AND DURHAM

Apart from Rievaulx in the North Riding of Yorkshire,³ blast furnace production commenced in the north of England after 1580, first with a furnace at Heanor in Derbyshire erected about 1582 by Sir John Zouch of Codnor. Subsequently furnaces and forges were built in an area extending along the eastern border of Derbyshire from Heanor to Sheffield. The first two blast furnaces in the immediate vicinity of Sheffield were on record by 1585. The most northerly furnace operating in the West Riding of Yorkshire before 1600 was on the border of the ancient Forest of Knaresborough and south-east of Harrogate. In the Sheffield area bloomsmithies were still in operation in considerable numbers.⁴

¹ Account Roll of the possessions of John Littleton, 1566-1570, Birmingham Reference Library No. 351958.
² PRO, Chancery Proceedings, Chas. I, D6/24.
³ Rievaulx furnace seems to have been built in 1576–77, which is indicated in the first account of 1577–78 (Be., No. 527) by various items such as the building of a new casting house and a new finery, of a new floodgate and a storehouse.
A furnace with lands in Thurgoland in the upper valley of the Don north-west of Wortley is mentioned in an indenture of 1567 (J. Hunter, South Yorkshire, vol. ii, p. 285, London, 1931); it may have been the bloomsmithy in the adjacent village of Oxspring.
⁴ E.g. at Emley and Oxpring, in the West Riding, accounts from 1584 to 1590, Sheffield, Duke of Norfolk's Estates Office, and at Totley, in Derbyshire, south-east of Sheffield, mentioned in 1574, Sheffield City Library MS No. 192, fol. 4; all three belonged to the Earl of Shrewsbury. In North Derbyshire there was a bloomery at Barlow in 1605 and in the
MAP IX. The iron industry in the Sheffield area in the seventeenth and early eighteenth centuries.


XVII English blast furnace in a cast-iron fireback dated 1656.
Expansion over the British Isles

Between 1650 and 1700 the iron industries of Derbyshire and the West Riding of Yorkshire moved westwards to the ore deposits which had already been worked in the Middle Ages. The main group of furnaces, from Bank to Chappel, were situated on the outcrop of the Tankersley ironstone. The two Derbyshire furnaces of Foxbrooke and Staveley were near the horizon of the Tankersley ironstone or its equivalent. Seacroft furnace near Leeds was near the outcrop of the Black Bed and Better Bed Coal and Ironstone. The two older furnaces at Kimberworth and Wadsley near Sheffield obtained their ores from Tankersley.¹

Evidence for the North East is very scarce. Possibly the iron ore of the Weardale in County Durham, mined in 1626, was smelted in a local furnace which may have been the Bishop of Durham’s furnace, operating in 1664.

HAMPshire AND FOREST OF DEAN

By 1600 the indirect process had been introduced in most of the iron-producing districts in England and Wales, but neither in Ireland nor in Scotland. Even in England there were still regions as in Hampshire, where no blast furnace was in existence despite the presence of high-quality ores.

However in about 1605 furnaces and forges were erected in Hampshire by Henry Earl of Southampton at Sowley near Beaulieu and at Titchfield near Fareham. The ironstone smelted was collected along the coast of the county; the ore used at Sowley was rich in iron content which, it is estimated, amounted to 50%.²

The late appearance of the blast furnace in a district in which iron-production never played an important part is comprehensible, but it is less so in respect of the Forest of Dean, which had been an important centre of iron-making throughout the Middle Ages. The main reason for the delay was the privileged position of the ‘free miners’ in the Forest, which ensured them a kind of corporate monopoly in respect of iron-mining, and ore-smelting in their bloomeries. A further reason was the Government’s desire to preserve the oaks of the Forest for more urgent uses such as shipbuilding; for the comparatively small consumption in bloomsmithies lessened the danger of timber depletion.

It was not until the reign of James I (1603–25) that blast furnaces were substituted for bloomeries, although the new method had reached


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the border of the Forest much earlier. In the valley of the river Wye between Whitchurch and Goodrich, in Herefordshire, a furnace had been erected by the Earl of Shrewsbury before 1575. First evidence, of a furnace at Lydbrook, on an eastern tributary of the River Wye and halfway between English Bicknor and Ruardean, is from the early 1590's, when a test was made of Osmond iron produced there from 'raw iron'. The furnace stood on the property of Robert Devereux, second Earl of Essex; after his attainder for high treason and his execution in 1601 this property was forfeited to the Crown.

On the opposite side of the Forest and near the estuary of the River Severn, there was a furnace not much later. It stood near Lydney, on the property of Sir Edward Wynter. In 1604 he obtained a licence to fell trees on his estate to convert them into charcoal 'for the makeing
and workeing of iron'. Two years later his ironworks at Lydney was described as consisting of a furnace and a forge.¹

The erection of blast furnaces within the Royal demesne of the Forest of Dean was being seriously contemplated in the years 1609 and 1610. In a letter of 26th April, 1609, George Moore, steward of Goodrich Castle in Herefordshire, which belonged to Gilbert, Earl of Shrewsbury, informed his master of plans being made for the erection of new ironworks in the Forest of Dean. He added that there were 'divers good rivers and mine of iron-stone in all parts of the same and the woods so stately and such planted, as will continue six furnaces and as many forges at least twenty or thirty years'.²

Such plans were very much in the air in those years. They even extended to a project to erect ironworks on English plantations in Ireland. In 1610 an ironmaster named Tokefield, who was partner in an ironworks on the river Shannon and who acted as agent for Sir Arthur Chichester, Lord Deputy of Ireland, to discover suitable sites for ironworks, stated that the Irish ore was 'not as yeldable as the English iron ore'. He therefore proposed that King James I, who had 'great stores of Woodes' in the Forest of Dean, should erect four furnaces in the Forest. The pig iron produced would be sent to Ireland via Bristol and worked there into bar iron.³ Tokefield's project was readily accepted by Sir Arthur and also by Sir Richard Morison, Vice-President of the Irish Province of Munster. Both advised the Earl of Salisbury, the Lord Treasurer and chief secretary of state, to set up a 'furnace or two in the Forest of Dean, and a forge or two in Munster to worke the sow iron that shall come from thence into bars.' Sir Arthur, however, did not conceal his fears lest Tokefield should have been too optimistic in estimating the total expenses for erecting an ironworks with stock as £1000. His doubts were based upon a statement by Sir Richard Boyle, one of the greatest ironmasters of his day, who later became the first Earl of Cork. Boyle, a shrewd and successful business man, estimated the expense as at least three times as high.⁴

Perhaps the large capital required induced the King to leave the financial burden to a man wealthy enough to bear it. This man was William Herbert, Earl of Pembroke. The Earl not only had vast possessions in the bordering county of Monmouthshire and in South Wales but also a considerable interest in the Forest of Dean, as he held the office of Constable of the Castle of St. Briavels 'with the keeping of the deer and woods there'.⁵ On 17th February 1612, he obtained as a Royal grant the right to erect furnaces and forges at St. Briavels and

¹ Gloucester, CRO, D421/T22.
³ PRO, State Papers relating to Ireland, vol. 228, No. 73A. Abstract: Cal. of the State Papers Relating to Ireland, 1608–10, p. 419. London.
in the Forest of Dean, to take up 12,000 cords of wood per year for charcoal burning at 4s. per cord, and to dig iron ore and cinders.\(^1\)

Subsequently, four furnaces were erected: Cannop and Park or Parkend in the centre of the Forest, Soudley on the eastern border, and Lydbrook. In addition, three forges were built at Parkend, Soudley, and Lydbrook. Building commenced immediately after the grant, and 1200 loads of timber were used for the erection of the works, including the necessary houses for workers and for storing charcoal and iron. The delivery of the 12,000 cords of wood granted to the Earl of Pembroke for charcoal burning started at the same time. The names of the four furnaces with three forges annexed are given in accounts of timber delivered to them in the years 1614–17. Three of the ironworks were situated almost in a straight line across the Forest, from Ross on the Wye to Lydney on the Severn. They were (from north to south): Lydbrook (furnace and forge), Cannop (furnace), and Parkend or Park (furnace and forge). The fourth furnace (with a forge) was Soudley, the site of which was farther to the east between Blakeney and Cinderford.

By an agreement of 3rd May 1615, the Earl of Pembroke made over his lease to Sir Basil Brooke. Sir Basil, however, worked only two of the ironworks, Parkend and Soudley, in partnership with Robert Chaldecott; Lydbrook and Cannop were operated by Richard Tomlins and one George Moore, apparently identical with the steward of Goodrich Castle in 1609 (see above). Each of the two groups of ironworks was supplied with half of the 12,000 cords per annum granted formerly to the Earl of Pembroke. The separation into two groups did not last more than six years. On 6th April 1621, all the ironworks within the Royal demesne of the Forest were leased to Philipp Harris and to Richard Challoner, a merchant of Bristol.

During the years 1628–29, two more forges were erected, one at Whitecroft, between Parkend and Lydney, the other at Bradley, near Soudley. From this date onwards the Crown owned four furnaces and five forges in the Forest of Dean. Some of the works leased to Sir Basil Brooke, George Mynne, and Thomas Hackett in 1627 were rather old and dilapidated and required considerable expenses for repairs and rebuilding. In 1635, when he applied for a new lease, Sir Basil estimated the expenses he had incurred up to then for building and repairing at £14,000.

An inventory of the works taken in September 1635 disclosed extensive building during the years 1631–34, but in spite of that all the ironworks, including the newly erected forges, were in a more or less poor state of repair in 1635. Probably it was this which induced the Crown

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to turn down Sir Basil's application, and to lease the ironworks to Sir Bainham Throckmorton of Clowerwall (i.e. Clearwell, north of St. Briavels), Sir Sackville Crowe, of Langhern in Carmarthenshire, and two Bristol merchants, John Taylor and John Gonning the younger, for twenty-one years commencing 24th June 1636. To save timber, not more than two furnaces and four forges, or three furnaces and two forges, were to be operated at the same time. The lease gave the four partners the exclusive right to produce iron within the Royal demesne of the Forest. All non-licensed ironworks erected in addition to the King's works, including 'footeblastes' (primitive bloomeries with bellows worked by foot which apparently still existed in the Forest), were to be pulled down. Sir Bainham and the other three lessees, who evidently were silent partners, had equal shares in the profits, but Sir Bainham got into debt with the two Bristol merchants in the course of the next four years. The mortgages he took from them at 8% had to be repaid out of his share of the profits.

In 1640, the partners had to surrender their lease because the whole Forest with all the ironworks and mines was leased to Sir John Wynter of Lydney, principal secretary to Queen Henrietta Maria, wife of Charles I. The lease, dated 20th February, included extensive rights such as the liberty to erect new towns and villages. It was, however, arranged that Wynter should demise the two furnaces at Parkend and Soudley and the four forges of Bradley, Parkend, Soudley, and Whitecroft, with sufficient supply of wood and ore, to Sir Bainham Throckmorton and his partners as under-tenants for six years. As Wynter already owned furnaces at Gunn's Mill, Lydney, and Rodmore, situated in a semi-circle around the eastern and southern borders of the Forest, he obtained practical control of almost the whole iron production of the Forest and its vicinity. A few years later in the Civil War, Wynter, who was an ardent Royalist, was attacked by the forces of the Parliament, and all the ironworks controlled by him were destroyed in 1644.

In 1653 a new furnace was erected at Parkend, but lower downstream towards the village of Parkend, and in the following year a new forge was installed at Whitecroft. Shortly afterwards Lydbrook furnace also was rebuilt. In 1673, however, the Treasury Board recommended the suppression of the two furnaces and their forges because of the 'destruction of wood and timber' in the Forest. They were sold for demolition to Paul Foley. Under the Foleys and their partners a great revival took place in the iron industry of the Forest of Dean extending into the adjacent districts of south Herefordshire, Monmouthshire, and into South Wales, which continued into the eighteenth century.1 Towards the end of the century eleven, i.e. almost half of the twenty-four

charcoal blast furnaces still working in England and Wales were in this area.¹

IRELAND

The main attractions for the English settlers interested in the industrialisation of Ireland in the seventeenth century were the abundance of fuel resources and the cheapness of native labour. In a survey presented in 1631 to Thomas Wentworth Earl of Strafford, who two years later was made Lord Deputy of Ireland, the country was described as wooded so well, that it would supply ironworks with charcoal for centuries. The cost of wood was stated to be negligible (‘not anything’). Cheapness of labour counted for most in the preparation of fuel for furnace and forge. The charges for cutting, cording, coaling, and carriage to the works were estimated at a fraction more than one tenth of those in England.²

The majority of the ores available in Ireland could not compete in any way with those mined in the Forest of Dean, so that throughout the whole period of iron-working in Ireland Forest ores were procured in considerable quantities. Of the various Irish ores three different sorts were distinguished.³ The first was bog iron ore, found particularly in Ulster. It was generally about one foot thick, and on the surface so that it could be mined at very small cost. The ore was rich in metal, but had to be mixed with one of the two other sorts, otherwise it would melt too rapidly and choke the furnace. The second sort, of inferior quality, was a hard ore called rock mine.⁴ It also had to be mixed with other ores, otherwise it yielded a very brittle iron ‘hardly fit for anything else but to make ploughshares’, according to Boate. This ore was exploited only in two mines during the first half of the seventeenth century; one was near Tallow, supplying Boyle’s ironworks, the other at Desart, in King’s county. The third sort was generally known as white mine or shell mine. It was found in mountains all over Ireland, but in the greatest abundance on the east side of Lough Allen in County Leitrim, in the mountains which the Irish called ‘Slew-Neren’, i.e. Mountain of Iron. This ore yielded the best iron in Ireland; tough, and ‘in many places as good as any Spanish iron’. The iron content was about 35%.⁵

Even before 1600 attempts had been made by English settlers to set up ironworks on Sir Walter Raleigh’s estates in County Waterford. The estates included almost all the localities of the district in which the

¹ List of 1790, Scrivenor, first edition, p. 361.
² In England £10 15. 8d., in Ireland £1 10s. 10d. per ton of bar iron made, Sheffield, City Library, Wentworth Woodhouse Papers.
⁴ An analysis of the ore smelted at Araglyn shows a highly siliceous low grade ore (SiO₂ 66.8%, Fe₂O₃ 13.08%, Al₂O₃ 7.92%, TiO₂ 0.66%, MnO₂ 5%). Analysis kindly supplied by Mr. V. B. Proudfoot of Queen’s University, Belfast.
iron industry prospered in the seventeenth century, such as Kilmackoe, Lisfinny, and the town of Tallow. The pioneers were two Englishmen from Kent who undertook to erect an ironworks in the county in 1591. A few years later they were followed by George Goringe and Herbert Pelham, the latter apparently being a member of the well-known family of Sussex ironmasters, but these do not appear to have been successful. The next evidence is from 1593, at which date Thomas Norreys of Moynallo, also on Sir Walter’s estate, obtained the right to cut wood and dig ore for his ‘iron mylles’ for twenty-one years.¹

Raleigh’s estates were overrun by the Irish in 1598 and the town of Tallow was burnt to the ground. The destruction accounts for the low price at which Richard Boyle, a young lawyer from Kent who later was made the first Earl of Cork, was able to buy the property in the district of Tallow, after Sir Walter had been attainted for high treason and his possessions forfeited to the Crown in 1603.² At Kilmackoe, in the vicinity of the former works at Mogeely, a new ironworks was erected by three partners one of whom was Thomas Ball, a London merchant. The approximate date is 1606, when a licence to ship ore from England ‘for the making of iron’ was granted. In 1619 the works was taken over by Richard Boyle who already had interests in it.³

Another early ironworks was erected on the Irish plantations of the East India Company of London on the river Bandon at a place near the Castle of Dondanier (now Dondaniel), in County Cork. The works was built for the Company by their master carpenter William Burrell of Deptford, in Kent, who had the lease, together with his partners, one of whom was Andrew Burrell, until 1619. The exact date of the installation is not available, but it was probably 1611, at which date Wm. Burrell held a licence for the transportation of iron ore from England to Ireland.⁴

The two most enterprising ironmasters, who controlled the largest number of works, were Richard Boyle and Sir Charles Coot.⁵ In


⁴ W. Burrell in his petition of 1619 claimed that he had placed ‘many English for the making of iron’ near Dondanier, PRO, State Papers relating to Ireland, vol. 295, No. 494. — For Andrew B. as partner see Grosart, 1st series, vol. 1, p. 41 (1614), and Cork MS, vol. 4, No. 131 — As late as in 1641, three parts of Dondanier were held by W. Burrell’s two sons, Cork MS, vol. 22, No. 101; vol. 3, No. 111 — The ironworks are recorded in 1613, APC, vol. 33, p. 107; Cal. State Papers relating to Ireland, 1611–1614, p. 381, and also in 1614 (reference to Burrell) Grosart, 1st series, vol. 1, p. 37.

addition to the above-mentioned furnace and forge in Kilmackoe on the river Bride, Boyle had a furnace at Cappoquin on the river Blackwater erected in 1615, and two furnaces at Araglyn, north-west of Lismore, built in the years 1625 and 1626. In 1634 he bought castle Skariff with ironworks at Tomgraney, in County Clare. In partnership with Sir Charles Coot, Boyle erected a double furnace and two forges in the district of Lough Allen, County Leitrim, in 1630. In this way the two partners secured the best ores available in Ireland for their furnaces. Sir Charles had a most profitable furnace at Mountrath, in County Leix. The position on the bank of the River Nore rendered it possible to make use of cheap transport by barge to the harbour of Waterford, whence his bar iron was shipped to London. By selling it in London he made a profit of 37%. Efforts were made to improve the techniques of iron-working in Ireland with the aid of skilled workers from abroad. At Tomgraney, County Clare, an ironworks was erected about 1632 by seven partners one of whom was Richard Rowley. He engaged sixteen Walloons from the bishopric of Liège who came to Ireland in 1633. The industrial development of Ireland was seriously interrupted by the rebellion of 1641; and Boate asserted a few years later that the Irish 'have broke down and quite demolished all... the Iron-works'. The reconquest of the country by Cromwell's armies prolonged the devastation.

The English iron industry in Ireland never regained the prosperity of the three decades before 1641, but it revived. In 1661 a new ironworks was erected at Enniscorlthy, County Wexford, at which 'many English workpeople' were employed. In Ulster quite a number of ironworks either continued to function or were re-erected, which applies to the south of Ireland also. Boyle's furnace at Araglyn was still active in 1655 to 1672, and again in the following century, the one near Skariff in 1683-85.

Compared with the boom period of the early seventeenth century the number of ironworks was no doubt much smaller after 1650, but it is difficult to imagine that it can have been quite as small as the figures given in 1672, according to which there were not more than ten blast

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1 Grosart, 1st series, vol. i, pp. 91, 145, 188 (Cappoquin); vol. ii, pp. 160-162, 166 (Araglyn, see also Cork MS, vol. 28, Nos. 44 and 46); vol. iv, pp. 22, 28 (Skariff).
2 Ibid., vol. ii, pp. 20, 312, 314; vol. iii, pp. 73, 75.
3 Sold at £16 to £17 10s. per ton, total expenses £10 or £11 per ton, Boate, p. 136.
4 'for the making of ordnance, barre iron and other thines', BM, MS, Rawlinson D918, No. 133; PRO Chancery Proceedings, Chas I, F26/14, and Ibid., C24/733/33. By their names most of the workers can be traced to Liège and vicinity, Yernaux, pp. 104, 250, 254.

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furnaces in the whole of the country and some twenty forges including the bloomeries. This seems impossibly few, even excluding the numerous Irish bloomeries known to have been in existence in earlier days.¹

**NORTH-WEST ENGLAND AND SCOTLAND**

Between 1650 and 1700 the red haematites mined in Cumberland and Lancashire were imported into Ireland in considerable quantities. Sir George Rawdon, for example, obtained Lancashire ore and Cumberland ore for his ironworks near Belfast from 1663.² The superior quality of these ores was appreciated in other parts of Britain also. As early as in 1614, John Waynewright, scythe maker of Wortley in Yorkshire, rented a cornmill at Prior Hall in Cumberland, which he converted into a scythe mill in order to make use of the iron produced from the native ore for his trade.³

Red haematites were exported to the west of Scotland in the early seventeenth century. The haematite ores which have been found near the ancient furnaces of the Loch Maree district in Ross-shire were not local ores. They strongly resemble the Lancashire ores of Ulverston. They were evidently imported from the peninsula of Furness.⁴ The origin of the iron industry on the shores of Lochmarae is somewhat obscure. All that can be said with some confidence is that it was established about 1610, possibly by Sir George Hay. He may have commenced operations at Fasagh as an extension of older ironworks. Remains of the foundations of another furnace situated about a hundred yards from the north shore of Lochmarae were still visible about fifty years ago but have now disappeared completely. The only remains still standing are those of a furnace called Red Smiddy, east of Poolewe.

According to a late statement (of 1786) cannon were cast at Red Smiddy in 1668, which may be considered the approximate date of the closing of the works, although it is said by local tradition to have been operated for a much longer period.

Foreign appreciation of the high-quality Cumberland and Lancashire ores which is implied in the extensive export trade, makes it rather surprising that in this region only two blast furnaces were erected before 1711. One was the furnace at Holme Chapel on the boundary of Lancashire and Yorkshire, the other was Cleator furnace.

² G. Benn, *A History of the Town of Belfast*, vol. I, p. 335 (310 tons in 1683, and 'in other years probably a greater quantity'). London, 1877. For imports from 1663 see note 1 above.
which, however, was only operated for a few years. The reason for the late appearance of the blast furnace was probably the remoteness of the district, in which bloomery production sufficed to satisfy the local demands of a predominantly agricultural population. It remained the process almost exclusively used until 1711, at which date the Backbarrow Iron Company was founded. Its first blast furnaces were installed at Backbarrow and Leighton in north Lancashire. At the same time ironmongers of Cheshire formed the Cunsey Company, and set up a rival furnace at Cunsey in the peninsula of Furness.¹ By 1750 a total of nine blast furnaces were active in the area, in addition to numerous forges.

THE FINAL PHASE

The distribution of ironworks in England and Wales in the early eighteenth century is shown on Map XI, which is based on the first detailed list of ironworks in England and Wales that we possess.² The list was compiled in 1717 by John Fuller, of Heathfield furnace, in Sussex, who obtained his information from William Rea, forgemaster at Monmouth. The list gives a total of a hundred and seventy-six ironworks with a computation of the annual output. Sixty of the works were furnaces (fifty-five producing), and a hundred and fourteen forges, apart from the Lancashire bloomeries, the number of which is not given. The list is fairly accurate, although a few works are missing such as Cunsey furnace, in Lancashire.

In the century preceding the date of the list noticeable changes had taken place. The most remarkable is the reduction of iron-working in the Weald which at least up to 1600 was supreme. The number of Wealden furnaces had diminished steadily, mostly since about 1660, with a fall from twenty-nine to fourteen in 1717, of which four were idle. The reduction continued progressively, so that in the list of 1790 only two blast furnaces in the Weald are mentioned, though a third furnace, at Robertsbridge, which is not listed was still active. In the south-west of England and south Wales the number of blast furnaces had increased after 1600 from fourteen to sixteen, owing mainly to the revival of the industry in the Forest of Dean and the surrounding area. In the same period an increase had also taken place in the Midlands (from eleven to thirteen). The industry of the Sheffield area including Derbyshire had held its position throughout the seventeenth century. In Cheshire and north Wales a marked increase is noticeable after 1650. In north Lancashire and Cumberland a completely new area of blast furnace production had been created after 1700, which still continued to expand in the middle of the century.

¹ Fell, pp. 223, 260, 265.
² Printed (with additional remarks) in Nunc. Tr., vol. ix, pp. 21–23, 35. For the following see also schedule above, p. 175, and a list of 1790, Scrivener, first edition, pp. 360–361.
Map XI. Furnaces and forges in England and Wales in 1717. Drawn by B. L. C. Johnson, M.A.

The Irish iron industry lingered on in the eighteenth century, but towards the close not more than two blast furnaces remained. These were in blast every third or fourth year and then for not more than three or four months in the year because of 'the great scarcity of charcoal'. These were at Enniscorthy, County Wexford, and at Mountrath, County Leix.¹

In the same century a revival of the charcoal iron industry took place

in Scotland.1 Exactly as in the first half of the seventeenth century, the main incentive was the abundance of wood for charcoal-making, combined with the advantage of cheap labour. The ores employed were mostly red haematites, partly from Cumberland, and partly brought by sea from the peninsula of Furness in Lancashire. The expensive transport over long distances was the chief handicap to the development of the industry. Between 1727 and 1730 four blast furnaces were erected. They were at Invergarry (built in 1727), Abernethy (1728), both in Inverness-shire, Glenkinglass on the shore of Loch Etive, Argyleshire (built in 1727 by the York Building Company of London), and Nether Wellwood, Muirkirk, Ayrshire (erected about 1730). Not one of these furnaces, however, survived after 1737. Fifteen years later Lorne furnace was erected at Bonawe, in Argyleshire, by the ironmasters of Newland furnace in Lancashire and supplied with ore from there. Argyll or Goatfield furnace, on Loch Fyne, in Argyleshire, was built in 1775 by ironmasters of Duddon furnace, Cumberland, and supplied with Lancashire haematite ore. Both furnaces continued after 1800.

A few other charcoal furnaces remained active after this date, such as Ashburnham, in Sussex.2 The last of the charcoal blast furnaces operated in Britain was the furnace at Backbarrow, in north Lancashire, which was worked with charcoal until 1920–21 when it changed over to coke.

2 In 1806, a total of 173 furnaces were in blast, of which 162 used coke and only 11 charcoal, Scrivenor, second edition, p. 99.
CHAPTER XII

THE EVOLUTION OF THE BLAST FURNACE

THE FURNACE BEFORE 1600

Neither picture nor description, nor any remains of the early English blast furnace are preserved. The only evidence relating to its structure is supplied by items referring to the building of furnaces and to repairs made. Since the items are numerous in the accounts of ironworks in Sussex from 1541 onwards and, at a later date, in those of Staffordshire and Yorkshire, it is possible to obtain some idea of the structure as it was in the sixteenth century, at least of the principal parts. Compared with the furnace of the early seventeenth century, hardly any difference is noticeable apart from the larger dimensions of the later furnace.

The main characteristic which distinguished the blast furnace from its fore-runners and remained an essential part until well into the nineteenth century, was the fore hearth which rendered it possible to ladle out liquid iron for foundry purposes. On Blès's picture painted in the early sixteenth century the moment is represented at which the casting of the sow had finished. The sow is still glowing at the end nearest to the hearth. At this moment the blast which had been stopped before tapping the molten iron, was put on again. As a result, a large flame issues from the fore hearth. The rising flame is clearly visible in the picture.

1 The furnace reproduced by L. F. Salzman, English Industries of the Middle Ages, p. 27, Oxford, 1923, and by M. B. Donald, 'Burchard Kranich (c. 1515-1578)', Annals of Science, vol. 6, Plate iv, London, 1950, both from a drawing in the Museum of the PRO, was a lead furnace erected in Derbyshire, near Duffield, about 1552 by Burchard Kranich, a German, PRO, Eschequer Special Commissions, Eliz. 24, Hilary No. 4. The furnace at Cwm Aman, near Aberdare, Glamorgan, remnants of which are still standing, is incorrectly ascribed to the sixteenth century (Arch. Cambrensis, 3rd series, vol. ix, p. 87); the tunnel conforms to Gunn's Mill furnace, Forest of Dean, of 1682.

2 For the following, cf. the illustrations, frontispiece, Plates xvi-xviii and Fig. 22.

3 For details of the fore hearth, see below p. 207, Fig. 23.

4 See frontispiece.

5 Percy, p. 492.
the slug is seen which has run out of the
fore hearth and coagulated. The English blast furnace also had a fore
hearth which is indicated by evidence from a very early date. For the
furnace of Robertsbridge, in Sussex, erected in 1541, a ladle was made
at the forge in 1543. With ladles the liquid iron was scooped out of the
open fore hearth. A tympl iron or tympl plate to protect the bottom and
outside edge of the tumpstone laid over the aperture of the hearth
leading into the fore hearth, and the two cast-iron plates termed buck
staves which supported the tympstone on both sides of the aperture
and extended into the fore hearth, are also referred to at an early date.

The furnace house frequently depicted by Bles was built over the
casting floor. The floor was in front of the hearth from which the liquid
iron gushed at the tapping and coagulated into the sot o or geuse in a
bed of sand. The earliest evidence of a house over the casting floor is
from 1547, at which date such a house was built of wood at the furnace
of Worth, in Sussex. In the early days the house seemed to have been
hardly more than a shed. At Rievaulx, in Yorkshire, one was extended
in length 'for castynge the sotes longer,' in 1577. It was built by a
carpenter and roofed with slates. Roofing with slates or tiles gradually
replaced thatching with straw in England.

The outer casing or shell of the furnace was formed by four walls
built of rough masonry and cemented together with mortar and, some-
times, with a mixture of clay and slag. Though built of strong stones,
the walls were liable to crack. Cracks were due to the combined effect
of the moisture to which the walls were exposed owing to rainfall and
snow, and the heat penetrating from within. To prevent cracking, walls
were given an extra support by a framework of wooden beams em-
bracing the shell. There was, however, a danger of the wooden frame-
work catching fire, especially if the walls of the furnace were too thin.
This was one of the objections raised in 1593 against the structure of the
furnace built by Thomas Proctor at Shipleyhurst, near Bradford, in
Yorkshire.

A combination of moisture from outside with the heat from within
was also liable to arise from the position of the furnace. Since a current

1 See Johansen, illustration facing p. 144; the slag is shown by its dark colour.
2 Pe., No. 379(1).
3 "Tympl irons' for Panningside furnace, wrought at Robertsbridge forge, in Sussex, in
1548 and 1553. Pe., Nos. 375 and 382(4) — "Casting of two buckstaves' for the furnace
mouth weinge 3 C(wts) 12 so(nes)'
at Rievaulx furnace in 1591; two buckstaves cast there in
1613–14, Be., Nos. 529 and 549 — For the position of the above-mentioned parts see
below, Fig. 23.
5 Be., No. 527.
6 Robertsbridge in 1544, and Panningside in 1549, Pe., Nos. 371 and 382(2).
7 First evidence of a framework is an item in the accounts of Panningside furnace of 1549,
referring to carpenters being paid 'for the settyng up of the tymberwork of the phurnace',
Pe., No. 382(2) — Illustration, see Plate xvii.
8 PRO, Eschequer Depositions by Commission, 35/6 Eliz., Mich. 34.

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of water was the only motive power for driving the bellows, the furnaces were erected quite close to the race of the water wheel. Such a position naturally constituted a considerable danger owing to ground moisture. If vapours rose from the ground underneath the hot furnace and penetrated into the hearth, the whole furnace was in danger of exploding. To prevent this, a proper device for drawing off ground water was indispensable. At first it consisted of trenches underneath the building. A ‘cross trench’, i.e. an X-shaped trench, was dug in 1542 before the body of the furnace at Panningridge was erected. A further means of protection against ground moisture was a trench dug all around the furnace.\(^1\)

The corner wall between the front aperture which led into the hearth and the side aperture for the bellows, was termed the pillar of the furnace. At Panningridge six loads of stone were required for making such a pillar in 1558. At the same time a new buttress was built against the back wall of the furnace as a support where the furnace adjoined the back race of the water wheel.\(^2\) It also served as a socket for a wooden bridge leading from the furnace-top across the water to the hill on the other side of the back race on which a bridgehouse stood. A bridgehouse was required for storing raw materials sufficient at least for the night, and to keep them dry. At Panningridge a bridge is mentioned in 1551; it was rebuilt three years later.\(^3\) A bridgehouse at Teddesley furnace, west of Canckwood, in Staffordshire, is referred to in 1582.\(^4\)

Between the walls of the outer casing and those of the inner cavity a space was left which was packed with stones of inferior quality set in sand or earth.\(^5\) This was one of the characteristics of the charcoal blast furnace from the early beginnings to the eighteenth century. Apparently cast-iron sows were built into the walls surrounding the inner cavity to support the tunnel, so that boshes and hearth might be rebuilt without breaking down the walls of the tunnel. Sows built into the walls are mentioned frequently in building accounts.\(^6\) The walls of the tunnel were of stone, but sometimes they were lined on the inside with bricks. The earliest evidence of a brick lining is in accounts of the furnace at Sheffield in Sussex, of 1546–49.\(^7\) In the Midlands brick lining also

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\(^{1}\) Pe., No. 373 — About the danger of explosion, see Plot, p. 163.

\(^{2}\) Pe., No. 382. For the dimensions of such a buttress, see App. XII.

\(^{3}\) Pe., Nos. 382 (3, 5, 6). A bridge was built of timber for the furnace at Oakamoor, in Staffordshire, in 1596. Middleton Papers.

\(^{4}\) ‘Tymber for planckes for the bridge and undersettinge the house’, Stafford, Wm. Salt Library, D.1734. A new furnace with a bridgehouse was built at Rievaulx in 1616, Be., No. 534. Both references demonstrate that the use of a bridgehouse was earlier and more general in England than presumed by Straker (pp. 81–82, 370, 387).

\(^{5}\) In 1555, Pe., No. 382(6).


\(^{7}\) ‘new making and mending the furnes with byrk within’, PRO, Exchequer, various accounts, Bundle 484, No. 19 — Arch. Je., vol. 69, p. 295.
The Evolution of the Blast Furnace

occurred, e.g. at Middleton, in Warwickshire, but it was by no means general throughout the country. In the building accounts of Panningridge furnace, in Sussex, a large quantity of stones is referred to, but no bricks at all, nor is there any evidence of brick lining at Rievaulx in Yorkshire.

A further characteristic which the early English blast furnace had in common with its successor in the seventeenth century was the open top aperture. The platform around it was covered with tiles. The aperture itself was of stone. As it was completely open, the gas was allowed to burn away. The strong heat of the flames rising above the tunnel mouth sometimes carrying up pieces of iron ore, were a frequent cause of damage to stonework and tiles. To avoid this, a new feature was introduced, at latest by the end of the sixteenth century—namely plates of cast iron laid upon the platform around the furnace mouth. The earliest evidence of this is in accounts of the furnace at Rievaulx, in Yorkshire of 1591, at which date the casting of four plates for the furnace top is referred to. This is the first evidence in history of such a device being used. More particulars are supplied by a description of the furnace at Leighton, in Yorkshire, erected in 1713, the top of which was covered with a large thick iron plate.

One subsidiary structure attached to the furnace is of particular interest: the shed on the platform of the furnace top. The earliest evidence of such a shed or small house is a reference to a wooden 'penthouse over the fornes' at Panningridge, in Sussex, in 1555. Such a penthouse is represented on a painting by the Flemish artist Lucas van Valkenborch who was born at Louvain, in Belgium, about 1530 and died at Frankfort/Main, in Germany, in 1597. The picture is reproduced on Plate XVI.

To place a building, even a small one, on the top of the furnace, required a fairly large platform. The penthouse at Panningridge must have been of wood, since a carpenter was employed to board it. For this reason it would have had to be placed a good distance away from the top aperture in the centre of the platform, so as not to catch fire.

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1 In addition to 200 loads of stone, 2,000 bricks were required for building the furnace in 1591, Middleton Papers.
2 293 loads of stone, in 1549, at Panningridge, Pe., No. 373 — 'leading stones for the furnace hearth and tunnel', in 1603, at Rievaulx, Be., No. 431.
3 Panningridge furnace, 1549, Pe., No. 382(2).
4 Jo., vol. 170, 1954, p. 326, Be., No. 529, the four plates for the furnace top were arranged as in one line and the fourth joined at a right angle, as it is shown in Plate xvii. For Leighton, see App. XVII.
5 'Paid to a carpenter for ye bordyng of ye penthouse over ye fornes', Pe., No. 382(6). — R. Evrard, Les Artisits et les mineurs d'or, pp. 55-56. Illustration Fig. 21, p. 57. Liége, 1955. The tapping of the iron by the founder depicted in Valkenborch's painting could not possibly take place on the water side of the furnace because of the detrimental effect of moisture. It would take place on the opposite side, where it could not be shown, because of the intervening furnace.
XIX Ruins of furnace at Sharpley Pool, Worcestershire. Photo kindly supplied by Miss M. Wright, Hereford.

XX 'Clearing the Hearth.' From a painting by Henri Blés, Collection of the Prince of Liechtenstein, Vaduz. By courtesy of the Verein Deutscher Eisenhüttenleute, Düsseldorf.
XXI A cast-iron gun of the reign of Queen Elizabeth I, Museum of Artillery in the Rotunda, Woolwich. There is a crown and the Tudor Rose on the second reinforcement. Length of gun, 9 ft, 6 in.; calibre, 7 in.; weight 59 cwt; 11 lb.
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A fence was constructed round the edge of the platform as a wind screen to prevent the flames from being blown about.¹

It is significant that on all of Blès's paintings ascribed to the early part of the sixteenth century, the top of the furnace is depicted as so small as to leave no space for any kind of building. The enlarged platform in the painting of 1580 shows an important development, in the shape of a larger furnace. No definite figures as to the dimensions of the early English furnace are available. But it is pretty safe to assume that the size remained the same from 1542 almost to the close of the century. This is borne out by the quantities of stone required for building the body of the furnace and the expenses incurred which remained unaltered during the period concerned.² Whether the increase in size extended to the height of the furnace is difficult to say, but it is probable. Judging by the dimensions of contemporary furnaces abroad and those of later English furnaces it is possible to assume an average height of approximately 17 to 18 feet for the English furnace between about 1550 and 1600.³

The dimensions of the water wheel and the bellows driven by it can only be surmised. The bellows of a blast furnace in the Italian Alps, north of Piacenza, had a length of 12 feet in 1460-64. Since the bellows of Burchard Kranich's lead furnace in Derbyshire were of this length in 1554, it seems probable that those of the English blast furnaces in the second half of the sixteenth century were about the same. The water wheel of Kranich's furnace was '15 feet high' which was possibly also the diameter of the wheel at the contemporary English furnaces for the smelting of iron.⁴

The hearth of the early charcoal blast furnace was very narrow, which was necessary in a low furnace to generate a temperature sufficient for the production of grey cast iron favoured on account of its tensility and ductility. The dimensions of the hearth in England prior to 1600 can only be surmised from conclusions drawn from the capacity and from contemporary furnaces abroad.

¹ At Rievaulx, in 1591, 'one payre of gaytes before the furnace tope for keeping the wynd from yt'. Be., No. 589.
² At Pannegridge, Sussex, 238 loads of stone in 1542, Pe., No. 373; at Middleton, Warwickshire, 200 loads of stone and 2,000 bricks which works out at the same amount, in 1591, Middleton Papers. Building expenses: Pannegridge (1542) £59 15s. 5d.; at Coddor, Derbyshire, approximately £60, in 1591.
³ After 1550, the furnaces in the German Harz were 18 to 19 feet high, Beck, vol. ii, p. 767. In the countries in which the English type of furnace originated they were still lower; in Belgium, 17 feet before 1800, Scrivenor, p. 240; in France, 17 to 18 feet still in the eighteenth century, P. C. Grignon, Mémoires de physique sur l'art de fabriquer le fer, p. 110, Paris, 1775. — For the furnace at Leighton, Lancashire, built in 1713-14 and not higher than 22¹⁄₂ feet, 237 loads of stone were used for the outer casing alone, which is the same as the total required for Pannegridge or Middleton and indicates that these earlier furnaces were much smaller. Barrow-in-Furness, Public Library, MS 186, p. 170.
⁴ Filaret, loc. cit., p. 472 — BM, Add. MS 6689, p. 114 (12 feet long and about an ell, i.e., 3 feet broad 'at the broadest end'), p. 118 (water wheel).
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The English furnaces of the sixteenth century produced one ton in twenty-four hours on the average. In the following century daily output increased to an average of from two to three tons, except in the Weald, in which hardly ever more than one and a quarter tons was produced in a day. Since the hearth of the Wealden furnace was about 3 feet high according to evidence from 1674, it may be concluded that it had approximately the same height in the preceding century, when production had been almost on the same level. This conforms to the dimensions on the Continent. In the German Harz, e.g., the hearth after 1550 was 3 to 3½ feet high with a diameter of 10 inches at tuyere level and 1 foot on the top where it joined the boshes. Such dimensions may be accepted also for the blast furnace in England prior to 1600.¹

There was, however, a tendency to increase the dimensions of the hearth in the interests of higher production which developed in England towards the close of the century. In 1587, 'a new furnace harth of a new facom' (i.e. fashion) was constructed at Rievaulx. After this date, the daily output which had been 13 cwts. in 1587 increased to 1 ton 2½ cwts. in the period 1591–92, and to an average of 1 ½ tons from 1603 to 1610.² The improvement implied in the output figures suggests that the nature of the new fashion was a wider hearth which ensured a greater capacity.³

A wide hearth, however, necessitated a higher furnace to generate the required temperature. There is no evidence of higher furnaces in this country before the subsequent century, when such furnaces appeared first in the Forest of Dean.

THE FURNACE IN THE EARLY SEVENTEENTH CENTURY

Conclusions about the character of the English blast furnace before 1600 have largely to be based upon conjecture. Better evidence is available for the subsequent period. The ruins of one of the furnaces erected in the Forest of Dean in 1612 were discovered in the course of an excavation in the Forest about 140 years ago. The celebrated ironmaster David Mushet saw the remains and described the site as being below York Lodge. Judging by the position, this was doubtless the Parkend furnace on Cannop Brook in the centre of the Forest, built in 1612. Hearth and boshes of the furnace were found complete. Un-

¹ Appendices IV and XIV (Ray, in 1674, 'around a yard') — Beck, vol. ii, p. 767 (Harz).
² Be., No. 878 — App. X.
³ The limitations of a narrow hearth are implied in instructions of about 1710 for the operation of a furnace at Löhnberg on the river Lahn, in West Germany, also erected by Walloons and accordingly of a similar type to the early English blast furnaces. If the hearth, it was said, was made too narrow, the smelters would have a good time; but the proprietor of the iron works will get too little iron ('zu wenig eisen'); the hearth was 1 foot 2 inches wide and 3½ feet high. State Archives at Wiesbaden, Dillenburger Archiv, L5, vol. 2.

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fortunately nothing is left of them now, but they are shown in an illustration supplied by Abraham Rees in 1820 (with explanatory text). The archaeological evidence is supplemented by a detailed description in an inventory of 1635 giving the state of four furnaces in the Forest of Dean at this date, and further by accounts relating to the building of a new blast furnace at Rievaulx in Yorkshire, in 1616.1

The earliest representation of the exterior of an English blast furnace is in the corner of a cast-iron fireback dated 1636 (see Pl. XVII).

According to the inscription on the top, the central figure of the fireback represents Richard Lenard, founder at the furnace of Brede in Sussex, who succeeded his father as tenant of the ironworks in 1605, and whose ancestors had come to England in 1514, evidently from Picardy.2 The founder is holding a heavy hammer, and various other implements of his trade are depicted. In between his feet there is a bullet, and a ladle for taking the liquid iron out of the hearth, and above is a weight with a hook. Below his right arm a wheelbarrow is shown containing a basket filled with charcoal, and there is an empty basket underneath. The shield in the top left-hand corner shows a smaller hammer, a chisel, a weight similar to the one between the founder's feet but smaller, and a pair of tongs. On the shelf in the opposite corner are three tankards, which were of hardly less importance to the furnaceman, since the conditions under which he worked must have given him a tremendous thirst which he needed to gratify at frequent intervals. It was customary to supply him with plenty of ale, as is shown by relevant accounts of the period. In the bottom right-hand corner of the fireback there is a fireback bearing the initials of the founder.

The most important item is in the bottom left-hand corner. This is the front of a furnace, the major part of which is visible, though there is no 'penthouse' on the furnace top. This however was not an indispensable feature. The furnace house with the door leading to the casting floor is depicted as very much smaller than on any of Henry Blès's paintings. This was probably done for the sake of the artistic effect, so that the body of the furnace should be more conspicuous. The body itself, square and tapering and built of large stones, is clearly shown, and also the framework of large wooden beams embracing it, interlocked at the corners. A similar framework was found at Parkend furnace in the Forest of Dean.

The representation of the furnace on the fireback of 1636 cannot give us any knowledge of the interior. It is however possible with the

2 Straker, pp. 341–342.
help of archaeological and documentary evidence to reconstruct a furnace as it was around 1620.

Upon the large bottom stone (A) the hearth was built of selected fire-resisting sandstone. The walls were vertical; about 1 foot high to the tuyere hole (B) in which the nozzles of a pair of bellows were placed. The portion of the hearth below the tuyere, i.e. the crucible in which the molten iron collected, was elongated into the working aperture (N) the roof of which was strengthened by iron lintels (M). The diameter of the hearth was 4 feet from the back wall (F) to the dam stone (K).

![Diagram of Blast Furnace](image)

**Fig. 22. Blast furnace, cross-section through casting aperture.**

The portion next to the dam stone was termed the fore hearth; it was open at the top between the dam stone (K) and the timp stone (G); these were protected with cast-iron plates termed dam plate and timp plate (H & L). Protection was necessary because through the gap left between them the founder worked with iron staffs.

The portion of the hearth above the tuyere expanded slightly upwards towards the top (C) where the hearth joined the boshes. The total height of the hearth was 4 feet. The boshes were 2 feet 6 inches high (from C to D); at their top (D) the interior cavity of the furnace was widest (6 feet). The shaft or tunnel (D to E) was 15 feet 6 inches high. The inwalls of the tunnel converged towards the top aperture or furnace 'mouth' (E) which was square. The total height of the furnace, the interior of which was square in cross-section, was 22 feet above the ground level (JJ). The platform on the top (20 feet square from P to P) was floored with bricks or tiles.
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To protect the hearth from ground moisture a chamber (O) was built underneath the furnace. It was of stone and roofed with a cast iron plate 4 or 5 inches thick. On top of the plate a layer of sand 6 to 9 inches thick was spread on which the bottom stone (A) of the hearth rested. The chamber replaced the cross trench of the early furnace. To prevent any moisture penetrating from the ground into the body of the furnace and endangering the structure of the hearth, vents or conical pipes were built in, which allowed passage to the damps into the open air. ¹

The furnace plant is very like that of the eighteenth century in France depicted in the illustration on Plate XVIII.

The furnace was inside a furnace house; the furnace house is frequently mentioned in the inventory of 1635 (App. XII). The furnace houses of 1635 had walls of stone, the height of which varied from 8 to 10 feet, and they were roofed with tiles. At Rievaulx furnace, built in 1616, the house was less extensive, comprising only the casting floor and a cabin for the keeper of the furnace, while a proper house for the bellows was built as an annex to the furnace. There was a similar arrangement at the two smaller furnaces in the Forest at Cannop and Parkend which, in addition to the two annex buildings, had a third for the furnace keeper. The two larger furnaces at Lydbrook and Soudley had very extensive furnace houses (189 feet in circumference at Soudley) comprising all the various parts such as the casting floor, the keeper's cabin, and a compartment for the bellows. At Rievaulx there was a house on the top of the furnace. In its main parts (stone walls, tiled roof) it conformed to the illustration. There was, however, one essential difference. A chimney (F in the illustration) is not mentioned in the building accounts. Apparently the roof had a gap in the centre through which the smoke escaped. ² In the inventory of the four Forest furnaces no house on top of the furnace is referred to, which is not surprising since many furnaces did not have it. ³ The low walls of the top aperture of the furnace were covered with cast-iron plates, referred to as 'tunnel plate' in the inventory of 1635, and as cast-iron 'furnace tope' at Rievaulx, where they were no novelty. The water wheel (O) was 23 feet in diameter at Lydbrook, and 22 feet at the other furnaces in the Forest of Dean. The bellows were 18 feet long and 4 feet

¹ At Parkend furnace, Forest of Dean, the chamber was termed the 'penthouse under the furnace', App. XII. A detailed description is supplied by Swedenborg (p. 17) — 'One pype for the vente of the harth' weighing 38 lb. of wrought iron for Rievaulx furnace, Yorkshire in 1591, Be., No. 529; a 'vent' is mentioned in the inventory of Frith furnace, Sussex, in 1637, Surrey AC, vol. xviii, p. 51. A cast-iron plate, placed on top of the chamber, was found at Darvel furnace, in Sussex, probably erected in 1649. The plate which is now at Hastings Museum is 4 feet long, 2 feet wide and 5 inches deep.

² A similar opening is shown in a German furnace plan made in 1706 and preserved in the Archives of the Count of Solms-Laubach at Laubach in Hessen, Mineralia, No. 9.

³ See illustration in Courtivron et Bouchu, Art des Forges et Fouriera à Fer, Section 3, planche 2, reproduced Johannis, p. 224.
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wide, which conforms to measurements of 1711.1 Across the water of the wheel race a wooden bridge led from the platform of the furnace to a bridgehouse (PP), with one broad side upon an abutment of stone to support it. The largest of the bridge houses in the Forest was at Cannop (48 feet long and 21 feet wide) with walls 9 feet high.

Compared with the furnace prior to 1600, distinct improvements had been achieved. The dimensions of the furnace were greater. The largest of the Forest furnaces, at Soudley, was 28 feet square at the base and 24 at the top, which indicates a height of 24 feet at least. Of one furnace only, which was at Lydbrook, the height is given: 23 feet, which remained the average height of the English blast furnace throughout the seventeenth century and later.2 The greater height allowed for a larger hearth, and so for higher production. One special improvement which is believed to have been first introduced in England is the arched roof over the apertures for casting and blowing. The first reference to such an arch is from 1623 and relates to the furnace at Rievaulx.3

The shape of the inner cavity was quadrangular in horizontal section and in this respect completely different from the modern blast furnace. Such a shape is clearly shown by a hearth and boshes discovered in the ruins of Parkend furnace in the Forest of Dean, which operated from 1612 to 1644. Rees, who described the ruins, remarked particularly on the 'quadrangular form of the interior, which was common to charcoal furnaces at that time'.4 His statement is confirmed by remains of another contemporary furnace which at the time of excavation disclosed the same shape. This was the furnace of Cradley, south of Dudley, in the Black Country of the Midlands. The furnace is first referred to in 1610, but since the ironworks at Cradley was destroyed by floods in 1622, it must have been the one re-erected after that date and worked by Richard Foley in 1636.5 Gloucester furnace at Lamberhurst in Kent, built in 1695, was of the same type as is shown in a drawing of 1734.6

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1 J. G. Nicholls, The Forest of Dean, p. 273. London, 1858 (from a different inventory the whereabouts of which are not known) — Fell, p. 227 (Backbarrow furnace, Lancashire, 1711).
2 In south Yorkshire 20 to 25 feet from about 1650 to 1750, *Necr. Tr.*, xxx, p. 62, but there were still exceptions, e.g. the furnace at Dolgyn near Dolgelly, Merionethshire, erected in 1718 had a base 16-17 feet square which indicates a height of not more than 16 feet (measured by Mr. D. R. Hagne of the Royal Commission of Ancient Monuments in Wales and Monmouthshire). Red Smiddy furnace, near Poolow, Ross-shire (operated around 1650) was about 16 feet high, *PRAS*, vol. xxii, p. 120 (stack 10 feet) boshes and hearth (measured by the author) about 35 feet high.
3 ‘Mending the furnace arch with clay and mortar’, in 1633. Be., No. 593 — At the furnace at Ruabon, in North Wales, the founder was paid 15d. per day in September 1661 ‘for 6 days helping the mason at ye arch and ye body of ye furnace’, NLW, *Chirk Castle*, F13/16 — Beck, vol. iii, p. 719 (arch first in England).
4 Filaret, loc. cit., p. 472 — B.M., Add. Ms. 6685, p. 114 (12 feet long and about an ell, i.e., 3 feet, broad 'at the broadest end'), p. 118 (water wheel).
6 Swedenborg, facing p. 159, reproduced by Straker, p. 78.
The quadrangular shape of the inner cavity was retained in England in a great number of furnaces in the eighteenth century and even after 1800 in some furnaces, e.g. in Derbyshire.\(^1\) It would not have lasted so long had it not been regarded as advantageous for smelting. In the opinion of the early founders the descending mass of the raw materials was less exposed to the danger of sticking to the walls in the upper region of the boshes in which the cavity was widest. They also claimed that a better circulation of blast-air was achieved. Both these advantages, however, were discounted in the late eighteenth century.\(^2\) The sharp angles where the boshes joined the tunnel (D in Fig. 22) retarded the descent of the charge which was necessary in dealing with the refractory ores of the carboniferous basin smelted in most of the English furnaces.\(^3\)

**IMPROVEMENTS AFTER 1650**

The change from a quadrangular to a circular shape for boshes and tunnel, a significant step in the evolution of the blast furnace towards the modern form, took place about the middle of the seventeenth century. England, however, was not the first country to introduce it. Its origin is somewhat obscure, but the new shape seems to have appeared first in Sweden some time before 1650.\(^4\) The first English furnace of this type, of which remains still exist, was at Sharpley Pool, parish of Astley, in Worcestershire, and was presumably operated by Andrew Yarranton after 1652.\(^5\)

The inner casing of the furnace (Pl. XIX) is cylindrical in horizontal section slightly narrowing downwards with an internal diameter of 4 feet at a height of 2 feet above water-level. It is about 1 foot 3 inches thick and what remains stands 6 feet above water-level. The inner surface is vitrified and fused together by the heat to such a degree that the joints between the stones are no longer visible, which indicates that there was no brick lining. These interior walls stand in the right angle between two walls of red sandstone which were at least 7 or 8 feet thick. They were the remains of an outer casing, which was apparently square. The space between the two casings is 9 inches on the western side, and may have been packed with sand. These particulars suggest a rather squat furnace body with a base of about 20 feet square and a height of about the same. On the north-west bank of the valley, about

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\(^3\) Lewis, vol. iv, p. 122 (statement by J. Cockshutt).

\(^4\) Beck, vol. ii, pp. 1292 et seq. According to Swedenborg, pp. 7, 12, 13, fifty or a hundred years before 1734, in which year he wrote, the more ancient quadrangular shape was still used even in Sweden.

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25 or 30 feet distant from the exterior wall of the furnace and practically parallel to it, runs a stone structure which appears to have been the abutment of a bridge carried horizontally from the bank of the valley to the top of the furnace. The height of the abutment is estimated at about 18 feet.

Unfortunately, the ruins of the furnace at Sharpley Pool in their present state are so scanty that no conclusion with regard to the upper structure is possible. An undated sketch relating to an unnamed furnace in the vicinity of Tunbridge Wells in Kent, and a hardly less crude drawing of a furnace in the Forest of Dean in 1678 are not very instructive either. Two characteristic features, however, are indicated: the square-shaped hearth and, in the drawing of 1678, the square shape of the narrow top aperture.

The top aperture or ‘mouth’ of the English furnace was kept very narrow, which was quite in keeping with contemporary furnaces in iron-producing regions on the Continent. The object was to prevent dissipation of heat from the tunnel, in which the heat reflected from the walls upon the ore. Before 1700 the diameter of the top aperture was between 1 ½ and 2 feet. Although the height of the furnace had mostly been raised by several feet in the meantime, the mouth still remained narrow. Even in the tallest furnaces such as those in the vicinity of Stourbridge, in the Midlands, with a height of 26 feet, and Gloucester furnace, in Kent, which was 28 feet high and considered to be 4 feet higher than any other furnace in the country, the diameter of the mouth was not more than 1 foot 10 inches. As late as the close of the century there were charcoal furnaces in north Staffordshire in which the diameter of the top aperture was not more than 3 feet.

The construction of the hearth, for which the founder was responsible, was very important. He selected suitable stones and directed the work which was executed by masons. The founder’s activity which was termed ‘laying the hearth’ is constantly referred to in furnace accounts. In England, the material generally used was fire-resisting sandstone.

The dimensions of the hearth increased with the height of the furnace. As it is shown above, the hearth in the Forest of Dean around 1620 was 4 feet high and 2 feet in diameter excluding the fore hearth (4 feet with fore hearth) which was a slight increase compared with the dimensions

1 Sketch reproduced by Straker, p. 80, but in the original drawing in BM, MS 5933, fol. 73, the shape of the interior is not quite as bulky as in Straker’s reproduction — App. XIV (1678).

2 Letter of 1675 referring to Lancashire, Phil. Tr., vol. xvii, p. 696.

3 Swedenborg, pp. 154–155. At Leighton furnace, Lancashire, built in 1713–14, it was 2 feet 3 inches square, App. XVII.


5 At Rievaulx, sandstones taken from the disused buildings of the Abbey were employed, e.g. in 1591, Ec., No. 529.
of the hearth in the sixteenth century. The increase continued, though very slowly. ¹

The manner in which the hearth was constructed is demonstrated in the following drawing, which represents an English hearth as it was in 1704.

After 1650 the height of the furnace began to be increased, first in the Forest of Dean.² This was possible because the firmness of the charcoal from the oak trees of the Forest meant that the limit usually set to

![Diagram of a furnace hearth](image)

**Fig. 23.** Furnace hearth at Pontypool, 1704 (based on App. XVI).
(a) bottom stone; (b) front aperture; (c) temp stone; (d) wind wall (dimensions of breadth not supplied, nor for e); (e) tuyere side; the tuyere was 11½ inches above the surface of the bottom stone; (f) back wall; (g) dam stone. The length of the space which constituted the fore hearth between the dam stone (g) and the temp stone (c) varied greatly, from 6 inches (1734, Swedenborg, p. 18) and 1 foot 6 inches (Derbyshire, in 1813, Pantologia, vol. vi).

the height could be exceeded, and a greater burden of ore charged without the charcoal being crushed.³

Around 1700 more alterations were introduced. In the ten furnaces of the Spencer group of ironworks, which extended approximately from Leeds and Barnsley in Yorkshire to the north of Derbyshire, iron bands

¹ Lamberhurst, Kent: width 14 feet by 4 feet (apparently including the fore hearth); Stourbridge: height 5 feet, width 13½ by 2 feet at the bottom and 14 by 2 feet 4 inches at the top, Swedenborg, pp. 154-155 (1734). In south Yorkshire, 1698 to 1736: height 5 feet, width 14 feet by 2 feet 4 inches, Raisbrick, in *New. Tr.,* vol. xix, p. 62. — If a furnace was destined for the production of larger castings, e.g. large guns, a hearth of greater dimensions was built. At Lamberhurst it was made longer by 1 foot and wider by 8 inches than usual, Swedenborg, p. 158.
² App. XIV.
³ D. Mushet, loc. cit., p. 47.
or girth were substituted for the wooden framework. The bridge house, originally built on a hill opposite the furnace, was placed upon the bridge, so that it adjoined the top of the furnace.

An improvement of considerable importance was the substitution of wooden box bellows for the leather bellows up to then exclusively used in the English iron industry. The wooden bellows or blowing tub consisted of two large close-fitting boxes, one of which was raised and lowered upon the other. They were kept air-tight along the cracks by very flexible wood and leather strips set on steel springs. The air which entered through valves into the lower box was forced out from the upper box through the tuyere into the furnace. In England wooden bellows were first introduced in the copper mills of Derbyshire and Staffordshire (before 1686), and in the early eighteenth century in ironworks in the Black Country.

Wooden bellows were more durable than those of leather, the frequent repairs of which constituted an expensive item in all the furnace and forge accounts from the sixteenth century onwards. They were also more air-tight. Despite their obvious disadvantages the old leather bellows were retained in many of the ironworks throughout the eighteenth century. At the well-known cannon foundry at Heathfield, in Sussex, for example, they were still used as late as 1748, although the proprietor John Fuller was well aware of their deficiencies, to which he referred in a letter by saying that one of his 'bellows has an Asthma this month'.

2 Ibid., p. 64 — Account of Redbrook furnace, Gloucestershire, 1699–1700, 'building that end of the house over the bridge next to the furnace', CRO, Gloucester, D.421/E9.
3 Plot, pp. 165–166, with an illustration facing p. 165.
5 Battle, Fuller MSS.
CHAPTER XIII
ORE, FUEL AND FLUXES

The materials which were fed or charged into the furnace (thus acquiring the collective name of the 'charge') consisted of ore, fuel, and fluxes.

ORE

During the whole period of the charcoal blast furnace there was no lack of iron ore. Although consumption was infinitesimal compared with the colossal demand of a modern blast furnace, it was very much greater than the consumption of the bloomeries in the preceding period. The bloomeries were more or less dependent on rich ores. The blast furnace was not confined to these but capable of producing a tolerably good iron even from ores of poorer quality because the ore remained longer in contact with fuel and fluxes. Accordingly when the blast furnace came into use the area of ore-resources was widened and mining restarted in many districts where a decline had set in during the late Middle Ages, as for example in the Weald of south-east England, the Midlands, and in the north.

METHODS OF MINING

Greater demand not only necessitated an extension of the mine fields, it also led to improvements in the methods of obtaining the ore. These however proceeded very gradually. At first they hardly differed from the methods applied in the Middle Ages and in many parts of the country they still remained the same even in the final period of the charcoal blast furnace.

A very primitive method was called 'scouring' which was still used in the eighteenth and even in the early nineteenth centuries. It was practised in south Wales and Monmouthshire at places where the Ironstone Beds underlying the coal field cropped out to daylight in the
brooks. On the side of the hill a trench about 4 or 5 feet wide was dug to a depth of about 14 feet until the lowest vein was reached. Above the trench a pond was made in which the water from springs, and also rainwater, was collected. As soon as the pond was filled, a floodgate was opened through which the water gushed into the trench, carrying away all the loose earth and leaving the lowest vein bare. Then the banks of the trench were undermined on both sides until a large mass of many tons fell down. After this, the floodgate of the pond was opened again and the water rushing down cleansed the heavier ore from the loose earth and clay which were carried down the brook. This method was very inexpensive and labour-saving because the ore was at once cleaned and made fit for the furnace. On the other hand it could only be applied with hard ores since the small particles of soft ore would be washed away with the earth adhering. The earth carried down the valleys caused great inconvenience to, and raised bitter complaints by, the farmers who saw their pastures transformed into waste land, the fertility of which would not be restored even after a rest of forty or fifty years.¹

The method most widely applied in the era of the charcoal blast furnace was to sink shallow shafts, which hardly differed from the mediaeval method of sinking bell-pits. A fairly detailed description of such a mine is supplied by a report on an iron mine sunk in 1531 within the Royal park of Clun near Llantrisant, in Glamorganshire. The shaft of the mine was 5 feet wide at the top and 30 feet deep. From the bottom a 5-foot wide level drift extended horizontally for 20 feet towards the east. Three men were employed. The hewer who split the rock with iron wedges and broke the ore with a steeled pick axe, another who cut the timber to support the roof of the drift and probably fixed it also, and a third who raised the ore to the surface, which apparently was done with barrels and a hemp rope (referred to in the accounts) perhaps wound over a windlass.²

Mining of surface deposits by digging small shallow pits was still the prevailing method throughout the seventeenth century, and remained so well into the eighteenth. Considerable numbers of bell-shaped pits—twenty-eight in an area of 790 square yards—were found in that part of modern Leeds which is north of the river Aire. They were sunk before 1700 to a bed of ironstone 20 to 30 feet below the surface.³ A shaft sunk in 1728 on Adgarley Green in Furness, in Lancashire, was not more

² PRO, SPD, Henry VIII, vol. 66. Two lead mines worked at the same locality had a depth of 18 and 42 feet respectively.
³ E. K. Clarke, 'Report on Bell Pits', Proceedings of the Society of Antiquaries of London, series ii, vol. xx, p. 262 — Between 1690 and 1756, the ore used by the Speenham group of ironmasters in south Yorkshire was mainly obtained from bell-pits, Raistrick, south Yorkshire, N eve. Tr., vol. xix, p. 56.
than 36 feet deep, with a drift 35 feet long at which distance it joined another shaft that had been sunk earlier.1

In south Wales the shafts were even shallower. As late as about 1750 they were not deeper than 18 feet because the miners believed there was ‘no Quantity (i.e. of ore) deeper under the Earth’.2

Although mining with bell-pits and shallow shafts of an average depth of 30 feet generally sufficed, there is evidence of some sort of deep mining, though not before 1600. The iron mine at Balliregan, in County Waterford, south Ireland, first mentioned in 1615, had shafts which were at least 60 feet deep.3 The deepest iron mines however, even in the later part of the eighteenth century, hardly ever exceeded 90 feet, e.g. those in Shropshire, in the peninsula of Furness, and in Yorkshire.4

With deeper mining a new problem had to be faced, i.e. drainage. In mines sunk in mountains horizontal drainage-tunnels called adits and driven from the valley through the hillside to meet the shaft at its bottom, sufficed to drain off the water. The moment, however, that shafts were sunk deeper than the drainage level different methods became necessary. They were found in the pumping devices used in the copper and silver mines in Tyrol, the north German Harz, in Bohemia, and in Hungary. In the course of the sixteenth century they were introduced in English copper, lead and tin mines.5 The first evidence of such a pump being used in an iron mine is supplied by an inventory of the mine at Balliregan, County Waterford, in south Ireland, of 1622, mine and pump having been in operation since 1615.6

The pump used at Balliregan was a rag and chain pump of the type which was used in the tin mines of Cornwall until late in the eighteenth century, and greatly admired by Cornish miners.7

The pump was operated by an overshot water wheel (A), the water being conducted to the wheel through 400 feet of wooden troughs (L). The axle (B) turned on cast-iron centres or gudgeons (C) fixed in the two ends of the axle and resting on cast-iron pillows (D), in England

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1 CRO, Preston, 1806/1, p. 290 and DDK 435/50 — Two pits sunk in Shropshire in 1796 were 48 feet deep, Lewis, Knights, p. 70.
2 Percy, p. 806.
3 Cal., SP, Ireland, Addenda 1625–60, p. 74. London, 1903. Other mines in County Cork sunk about 10 years later also had 60-feet deep shafts. SP, Ireland, Addenda 1625–60, p. 74. London, 1903. In Sussex some of the mines which were generally between 4 and 40 feet deep seem to have attained a greater depth by 1674, Straker, p. 44.
6 App XI. See also reports on the mine of 1618 and 1622, Cork MSS, vol. 9, No. 23, and vol. 12, No. 136 (with a very crude drawing).
7 R. N. Worth, Historical Notes concerning the Progress of Mining Skill in Devon and Cornwall, p. 30. Falmouth, 1872 — For a detailed description see Agricola, p. 188, and VCH, Cornwall, vol. 1, p. 545.
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termed boits. An iron chain (G) broadened at intervals by knobs (I) of cloth stiffened and fenced with leather, turned around a rag-wheel (E) which was furnished with iron spikes (F; 'thorns' in the inventory) that served to keep steady the chain. By means of the knobs the chain forced up a stream of water through a wooden cylinder (K) which had been made by a borer. The cylinder was surrounded by a planked pump-shaft (H).

Fig. 24. Rag and Chain Pump.

(A) wheel; (B) axle; (C) journals; (D) pillows; (E) drum; (F) clamps; (G) drawing-chain; (H) timbers; (I) balls; (K) pipe; (L) race of stream.

From Agricola de re Metallica.

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In 1622 two rag and chain pumps were at Balliregan; one was in action, but the other, called the old one, was idle. The new pump had a chain 105 feet long; that of the old one was 140 feet long. The cylinders of both pumps were of equal length (40 feet). In the inventory reference is made to a third rag and chain pump which was only 10 feet long, had a chain 18 feet long, and was worked by manual labour applied to the handles. Apparently there were three devices: a hand-pump, a pump operated with a water wheel and later a new pump. To begin with the hand-pump appears to have sufficed. When the shaft was driven deeper manual labour turned out to be uneconomic, because a twenty-foot pump required five or six men to move the wheel. Work was so strenuous that they were unable to operate for more than five or six hours a day. On account of hard work, aggravated by the scanty dress of the labourers, who worked naked apart from loose trousers and were constantly splashed by the water pumped up, mortality was very high. A remedy was found by applying water as motive power. At the outset, however, this did not prove satisfactory, because the water supply turned out to be insufficient in the dry summer of 1618. As a result the ore of the bottom vein could not be mined because the wheel did not force out the water, and the miners had to open a drift at a higher level which was 'a dead charge' until they came to the ore. This was probably why the old water wheel was replaced by a new one. The new pump had a water wheel supplied from a pool in which a quantity of water was stored, against the possibility of dry weather. After this improvement the pumping device appears to have operated satisfactorily, for the output was quite substantial judging by the amount of ore sent to the furnaces at Cappoquin and Kilmackoe in County Waterford in 1622.

The difficulties experienced at Balliregan were by no means confined to the mining of iron ores, but quite general. In the sixteenth and seventeenth centuries numerous patents for improving the drainage of mines were granted and considerable expense incurred, but no great success was achieved until the application of the steam engine to the draining of water from the mines commenced in the early eighteenth century.

A further problem which became acute the moment deep mining commenced, was ventilation. In small and shallow mines in which the drifts or levels did not extend very far, the shaft that served for haulage and for the descent and ascent of the workers sufficed for ventilation.

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1 Cork MSS, vol. 9, No. 23.
2 Average of 626 tons per quarter compared with 545 tons per quarter in 1621, Cork MSS, vol. 12, No. 94 and vol. 13, Nos. 104 and 158.
3 Lipson, loc. cit., vol. II, p. 124 — The introduction of steam engines for draining mines was not extended to all the mining districts in eighteenth-century England. In Furness, in Lancashire, e.g. as late as in 1840, Lindale was the only place where such an engine was used, Fell, p. 76.
Adits also assisted in this respect. If however the drifts or levels extended to any considerable distance, special air-shafts were sunk or old disused shafts were re-opened for ventilation.\(^1\) To obviate the necessity of a frequent sinking of air-shafts, which caused considerable expenses, a new ventilation device was introduced by one Thomas Bushel, first in the lead mines of Cardiganshire. It was a German invention for blowing air with bellows through a lead pipe into the tunnel.\(^2\) Apparently a similar device was used in iron mines also, e.g. in Furness, Lancashire, in the eighteenth century. The windmill, or ‘wind engine’ at Plumpton referred to in 1763, seems to have been used for such a purpose, as air pipes, air shafts, and ‘blowing bellows for air’ are mentioned in connection with it.\(^3\)

The dress and equipment of a miner in the seventeenth and eighteenth centuries are represented in the crest on a brass plate in the floor of Clearwell Chapel in the Church at Newland in Gloucestershire.

On his head the miner wears a cap or ‘woollf’. His coat is described in the middle of the eighteenth century as a ‘crimson flannel shirt’.\(^4\) He wears short leather breeches tied with thongs under the knee. (Shoes are not visible on the brass plate, but marks of shoes have been discovered on the beds of excavations.) At his back hangs a wooden billy or mine-hod on a shoulder-strap fastened to the belt. In his right hand he is holding a small pick.\(^5\) The pick is pointed at one end and flat at the other, which latter served as a hammer to drive wedges into the rock.\(^6\)

Deposits of iron ore were generally explored by trial-shafts. The high cost of sinking these led to the introduction of boring with iron rods. Although the origin of this method is obscure, it seems to have been used in English coal mining between 1600 and 1615.\(^7\) In the British iron mines, however, exploration by boring was still rare in the eighteenth century. Although boring was known to the Knights, they still preferred the method of sinking shafts in the middle of the century in their mines in Shropshire and Worcestershire.\(^8\) In Furness, Lancashire, the first reference to boring is from 1780.\(^9\)

The ancient method of breaking the rock by driving wedges into it with the pick, continued throughout the seventeenth century. Another

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\(^1\) ‘sinking a Wind Pitt’, in south Yorkshire in the early eighteenth century, Raistrick, loc. cit., p. 57 — First evidence of a special air-shaft (30 feet deep) is of 1586-87 at which date it was introduced by a German in the silver mine of Cardiganshire, NLW, MS, Holyhead, No. 26, fol. 81.

\(^2\) D. J. Davies, *The economic history of South Wales prior to 1800*, p. 72. Cardiff, 1933.

\(^3\) Fell, pp. 77, 82.


\(^5\) Hart, p. 25.

\(^6\) Fell, p. 79 (Lancashire), the iron head of the pick was 16 inches long in the eighteenth century.

\(^7\) J. U. Nef, loc. cit., vol. ii, p. 446.

\(^8\) Lewis, Knights, p. 71.

\(^9\) Fell, p. 78.
method also still used in the same period was to split the rocks by heating with wood fires. Fire-setting had also been used in Antiquity and was described by Agricola in the sixteenth century. The danger of smoke being driven upon the miners by a sudden change of wind and suffocating them, required special precautions. The miner was not allowed to use fire before four o’clock in the afternoon and even then only after ‘giving his Neighbour lawful warning thereof’. Despite its danger, which was increased by the lack of adequate ventilation, splitting by wood fires had not completely fallen into disuse in the late eighteenth century.

In the same century this method was gradually replaced by blasting with gunpowder, first applied in Freiberg, Saxony, in 1610 but not used in England before 1670, and then only at copper mines in north Derbyshire. The exact date of the first gunpowder blasting in iron mines in Britain is obscure, but it does not seem to have occurred before 1700. In the peninsula of Furness in Lancashire it was used first at Adgarley in 1722, yet even at the end of the eighteenth century gunpowder was not much used.

ORE DRESSING

To make the ore from the mine fit to be charged into the furnace, it is submitted to a process of preparation called dressing. In the period of the charcoal blast furnace the various stages of preparation were basically the same as they had been in the medieval iron industry. The available evidence as to how it was done is, however, much more detailed.

Washing, whereby the ore was cleansed from earth and clay, was still practised in the seventeenth and eighteenth centuries in parts of Britain. Another method was weathering: the ore dug up at the mine was left in a heap and exposed to the weather for a considerable time. At Rievaulx, in Yorkshire, it was the rule as early as 1541 that the ore, after it had been ‘gathered’, was exposed to the weather for at least half a year so that it could lose its earthy parts, otherwise ‘ther will be

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1 Forbes, pp. 52–53; Agricola, pp. 119–120 (with illustration) — Plot, p. 134, describes it as setting ‘great fires to soften the rocks to make them yield to the pickaxe’.
4 R. N. Worth, Historical Notes Concerning the Progress of Mining, p. 17. Falmouth, 1872 — Plot, p. 165.
5 Fell, p. 81.
6 For Yorkshire between 1650 and 1750 see Raistrick, loc. cit., p. 57 — For south Ireland, see letter of 1660 in which the clerk of the Earl of Cork’s ironworks reported that before starting a new mine ‘a pond for the cleaning away of earth about it’ [i.e. the ore] was made, Cork MS, vol. 31, No. 90.

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much losse in cariage' of it to the smelting place.\textsuperscript{1} Great importance was attached to weathering in the eighteenth century. Two well-known English ironmasters, John Cockshutt and John Wilkinson, were of the opinion that the ore improved through exposure to the influence of the weather for ten or fifteen months, because afterwards 'it melts more kindly' whilst 'new ore falls down lumpish and dull' in the furnace.\textsuperscript{2}

The various stages of the subsequent preparation of the ore for the furnace were much the same as in previous centuries: burning, breaking, and washing the small ore.\textsuperscript{3}

Burning, i.e. roasting, in the eighteenth century frequently termed 'calcining', was of particular importance because it eliminated sulphur to some extent. For this reason Cockshutt and Wilkinson held that calcining, although not necessary for all ores, 'can do hurt to none; all ores yield better iron when calcined', because, as Wilkinson said, 'bad qualities of the ore should be destroyed before it goes into the furnace; afterwards it is too late'.\textsuperscript{4}

Roasting was performed in England in two different ways, i.e. either on the open ground, which was the older method, or in kilns. The fuel was wood, either alone or mixed with peat, or pure peat—as in the north of Lancashire—or mineral coal, but most frequently it was small charcoal, called braise or braize.\textsuperscript{5}

The procedure of burning ore on the open ground was as follows: a layer of braize was placed at the bottom 3 or 4 yards wide, 5 or 6 yards long, and 3 or 4 inches deep. On this bed the ore, stratified with more fuel, was piled up to a height of 5 or 6 feet, the larger pieces below and the smaller towards the top. As the heat ascended from below a smaller quantity of fuel sufficed in the upper part. Ore-burning took from

\textsuperscript{1} Be., Misc. MS, 106.
\textsuperscript{2} Lewis, vol. iv, p. 81; vol. v, p. 27.
\textsuperscript{3} The three stages are frequently enumerated in this order, e.g. in an account of Sir Henry Sidney's ironworks in Glamorgan of 1569, Pet., No. 397 — Burning was the term almost generally applied in the sixteenth and seventeenth centuries, Be. and Pe., passim, Ray, p. 134. In seventeenth-century Staffordshire the expression 'annealing' was in use, Plot, p. 161.
\textsuperscript{4} Lewis, vol. iv, p. 81 — Swedenborg (pp. 3, 41) was of the same opinion. The elimination of sulphur by calcining began to be realised in about 1700 by the ironmasters in England. Ch. Leigh, The Natural History of Lancashire, Cheshire and the Peak of Derbyshire, p. 83, Oxford, 1700 ('roasting the ore till the sulphur is sublimed'). The earlier ironmasters did not seem to be aware of it; Ray in 1674 noted only that the use of 'burning' was to 'mollify' the ore so that it could be crushed more easily, Straker, p. 44.
\textsuperscript{5} At Rievaulx (Yorkshire), in 1591, 'riving i.e. splitting of wood for burning of ore'; in 1605, seventeen loads of peat in addition to wood, Be., Nos. 529 and 881 — Ray (in 1674 for Sussex) refers to 'small' charcoal, and so does Plot (in 1686, for Staffordshire), p. 161, adding, however, that wood and mineral coal were also in use for roasting the ore. Mineral coal was applied, e.g. at Lawton furnace, in Cheshire, 1666–1711, Johnson, p. 61. According to a statement by Cockshutt, braize was always used in Yorkshire, in the middle of the eighteenth century, Lewis, vol. iv, p. 87. In the same period, mineral coal was used for burning in Shropshire (Coalbrookdale), the heaps being piled in the same manner as with braize, Lewis, vol. v, p. 7; in Monmouthshire it was proposed by Hanbury in 1704, App. XVI.
twenty-four hours to several days according to the weather. Generally 27 bushels of braize were sufficient to burn or calcine 60 bushels of ore.\(^1\)

Roasting in the open air in piles stratified with fuel was the method which, by all the available evidence, was most widely used in the British charcoal iron industry of the sixteenth century. In the seventeenth and eighteenth, however, kilns also were in use.\(^2\) Although the action of the fire was more uniform in kilns, it was believed that in the open heaps the freer access of the air contributed more effectively to the elimination of sulphur.\(^3\)

The use of kilns resembling ordinary lime kilns appears to have started in the Forest of Dean where such kilns were in existence at the furnaces of Cannop and Parkend as early as 1635. The kilns were walled in all round, leaving only a small door at the bottom for kindling the fire and withdrawing the calcined ore. At Cannop the walls of the kiln were strengthened by five pigs of iron built into them.\(^4\) From the Forest of Dean the use of ore kilns seems to have extended into south Wales and Monmouthshire where John Hanbury had such kilns in 1704. In the early eighteenth century kilns were introduced into Lancashire. In all these parts the kilns were placed near the furnaces, not near the mines as in France.\(^5\)

By ‘burning’ the ore suffered a loss of weight. According to a statement made by John Hanbury of Pontypool in 1704, a bushel of raw ore obtained from the mine and weighing 4\(\frac{3}{4}\) cwt. lost 50 lb. in weight through roasting.\(^6\) But although the ore lost weight, it did not lose its bulk which was reduced at the next stage of preparation, called ‘breaking’, i.e. ore-crushing. The narrow top aperture and throat of the ancient blast furnace meant that ores must not be too big. In the eighteenth century the size regarded as most appropriate was that of a walnut or a pigeon’s egg. Size was important. Too big pieces of ore would pass right through the furnace and smelt on their surfaces only. On the other hand if reduced too much, the powdery parts would fill the interstices between the coals and impede the generation of sufficient heat for smelting. This would waste fuel.\(^7\)

\(^1\) Lewis, vol. v, p. 5.
\(^2\) Although ‘burning’ of ore in ‘ore pits’ is frequently referred to there is no reference to ore kilns in the accounts and documents of the sixteenth century. By Ray’s description roasting in open heaps seems to have been the method used in the Weald in 1674. The same applies to Staffordshire in 1686 (Plot, p. 161: ‘upon the open ground’). For the eighteenth century see Swedenborg, p. 156; Raistrick, loc. cit., pp. 57, 62; J. Pilkington, *A view of the Present State of Derbyshire*, vol. i, p. 135 (‘in the open air’). Derby, 1789. Wm. Nicholson, *A Dictionary of Chemistry*, p. 582, London, 1795, refers to both methods.

\(^3\) Lewis, vol. v, p. 7.

\(^4\) App. XII.


\(^6\) App. XVI — In Sussex the loss was still greater, i.e. a load ore (16\(\frac{1}{4}\) cwt.) after burning was reduced to 11 cwt. 40 lb. at Heathfield, in 1738, Sussex AC, vol. LXVII, p. 30.

\(^7\) Lewis, vol. v, p. 3.
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The ore was broken by manual workers called ‘mine breakers’ or ‘mine crackers’ using small hammers.¹ Ore-breaking by stampers moved by a water wheel came into use in England at a fairly late date, apparently not before 1700; it was feared that they might be all too effective and pulverise the ore. John Hanbury of Pontypool, in Monmouthshire, was still uncertain about the usefulness of ore-crushing by heavy stampers. Although aware of their advantages he still feared that the furnace might be ‘clogged by the smallness of the mine’.²

After the ore had been crushed, the smallest particles were separated from the rest by coarse sieves. The siftings (these only, never the large pieces) were washed free of earthy matter. In the eighteenth century washing was performed on an inclined plane on which perpendicular boards were fixed ‘somewhat like the steps of a ladder’. The earthy parts ran down with the water whilst the metallic parts remained at the bottom, the heaviest in the upper and the lighter in the lower partitions. Washing however was not applied to all of the English ores because some of them were so rich that they required no separation from earthy matter but rather an addition of it.³ Prior to the eighteenth century a simpler appliance served for washing the siftings. It was made of a hollowed log and was called the log washer. In January 1592, the founder at Rievaulx furnace and some helpers were given bread and ale for two days’ digging and setting up of a wooden ‘trough for washing of ore’. By an item in the accounts of the same year, it is shown quite clearly that the ore washed in the log washer was small ore called minion, i.e. the siftings of ironstone which had been roasted.⁴

After being dressed, the ore was frequently stored in a house to protect it from the deleterious effects of rain and snow.⁵

SUPPLY OF WOOD FOR CHARCOAL

The main fuel for furnace and forge continued to be charcoal until well into the eighteenth century. In the sixteenth century, which is character-

¹ At Rievaulx, e.g., one Robert Owram was paid 4s. 8d. weekly for ‘breaking of ore and wheeling it to the furnace’, in 1613–14, Be., No. 459. The iron part of the hammer had a weight of 3½ lb. in 1591, ibid., No. 529.
³ Lewis, vol. v, p. 21 — At Backbarrow and Leighton furnaces, in north Lancashire, ‘burning’ and ‘breaking’ is frequently referred to, but never crushing. The ore mainly was the rich haematite of the peninsula of Furness. Rawlinson MSS, Nos. 186 and 188.
⁴ Be., Nos. 529 and 530. At Oakamoor, in Staffordshire, the founder was occupied with ‘washing mynien at the furnace’ in 1597, and again in 1609 (sifting and washing ‘mynien’), and 1605 (sifting ‘menien’). Middleton Papers. Washing of ‘small mine’ frequently is referred to in later accounts, e.g., at Kilmackoe furnace, south Ireland, in 1608, Cork MS, vol. 2, No. 100, and at Rievaulx in 1636, 1637 and 1641, Be., Nos. 337 and 339 — See also Plate XVI (below the wheel).
⁵ ‘Removing of burnt ore into a house to keep it dry’ at Rievaulx in 1613–14, Be., No. 459; the ‘ore house’ is mentioned already in 1602, Be., No. 431.
ised by a relatively rapid industrialisation, the supply of fuel for charcoal became a much discussed problem. At the beginning of the century the country was still well wooded, as described by John Leland after his journeys through England and Wales in the years from 1535 to 1543. ¹

A change for the worse started with the dissolution of the monasteries in the late fifteen-thirties, and the sale of their possessions including large tracts of woods which had been well preserved hitherto. The majority of the new owners who acquired the property of the dissolved monasteries, and not less the tenants of property retained by the Crown hastened to realise money by the sale of timber growing on their newly acquired soil. ² It was very profitable to sell the wood to the iron industry in mining localities such as the Weald. As the Wealden industry increased rapidly year by year, considerable quantities of wood were consumed, which resulted in a scarcity serious enough to attract public notice by the middle of the century. The complaints lodged by the towns of Hastings, Rye, and Winchelsea in 1548 against the Sussex ironmasters because of wholesale destruction of timber resources were not without foundation, although the complainants’ primary object was to safeguard their own extensive export trade in timber and fuel to Picardy, where England held the towns of Boulogne and Calais with some of the hinterland. ³

There is ample evidence of devastation of woods and forests caused by excessive demands for ironmaking. In 1553, e.g. the Forest of South Frith between Tonbridge and Tunbridge Wells, in Kent, was farmed out for forty years to obtain charcoal for ironworks. An inquisition held in January 1571 disclosed that ‘the woods of all the premises are well nigh spent’ with the effect that 4093 acres were turned into ‘heath and barren land’. ⁴ Such acts of destruction were by no means confined to the Weald. A striking example is the spoil of Cannock wood, in Staffordshire, which supplied Lord Paget’s ironworks situated in the vicinity. After his attainder for high treason, the works were demised to Fulke Greville, the friend of Sir Philip Sidney, in 1589. In the nine years following in which Greville held the works, the woods were spoiled to such a degree that witnesses called in 1610 unanimously deposed about Canckwood ‘there was great store of woodes there growing at the tyme of Sir Fowke Grevills first entrance which woods are nowe wast land spent at the ironworkes’. ⁵

Big entrepreneurs in the iron industry such as Richard Foley who

³ Straker, pp. 113 et seq. — The preamble to the Statute of Edward VI, issued in 1552, also referred to ‘greate scarcity of Wooden’, Statutes, vol. i, p. 171.
⁴ PRO, Exchequer Special Commissions, No. 1093.
⁵ Stafford, Wm. Salt Library, D1734 — PRO, Exchequer Depositions by Commission, No. 4533.
operated five furnaces and nine forges and slitting mills in the Midland counties of Shropshire, Warwickshire, and Worcestershire, were first of all objects of bitter complaints about destruction and waste of wood. In 1636 Foley was accused of having felled 19,320 trees which should have been reserved for shipbuilding, and of having consumed yearly 300,000 loads of wood in his various ironworks within the seven preceding years, which account was based on depositions by witnesses. A serious accusation was that he had caused the felling of 10,000 saplings to the detriment of the future development of the woods.1

That timber trees suitable for shipbuilding would be burnt for charcoal was the strongest and most effective argument in the various complaints because 'shipping is the wallis' which prevented enemies from invading England, as was urged in the suit against Foley. This applied with special force to the Forest of Dean, the splendid oaks of which supplied timber for ships both for the Navy and the merchant fleet. In 1634 merchants and shipowners at Bristol complained that in the preceding twenty years one half of 'the goodly forest' had been destroyed by the demands of the local iron industry, so that they were constrained to buy 'Dutch-built' ships. The complaints were justified, for the cutting of trees for charcoal to be used at the Earl of Pembroke's ironworks had caused great devastation in the Forest.2

The reiterated complaints about destruction must however not be taken entirely at their face value. John Norden writing in 1607 reported an abundance of timber trees in various counties such as Derbyshire, Cheshire, and Shropshire in which iron was worked extensively. From the 'welwooded' counties he did not even exclude Sussex, Surrey, and Kent, 'the grand nursery of trees, especially Oake and Beech', although he was well aware of the amount of destruction which had taken place in the thirty years preceding the writing of his report, which he attributed mainly to the manufacture of iron and glass. In Ireland also, according to Boate's statement, after four decades of large-scale depletion of the woods through the export of timber and by ironworking, 'many great Woods' were still left in 1640. Even in the south where 'the greatest destruction' was done by the Earl of Cork, he found that 'some great woods are yet remaining'.3

Shortage of wood would have imperilled the iron industry earlier and to a greater extent than it actually did, had it not been for two

1 PRO, SPD, Chas. I, vol. 319, No. 109; vol. 321, Nos. 42, 63, 64. Abstracts: Calendar of State Papers, Domestic Series, of the reign of Charles I, 1625-36, pp. 400, 435, 441 — The final sentence is not recorded, but it appeared to be a fine of £1,000 suggested by the Lord Chief Justice, to which the Archbishop of York agreed but proposed an additional £200 to be paid 'to the informer', which was not unusual in those days.


measures which counteracted deforestation. One of these was a law which restricted the cutting of trees for charcoal required by ironworks. A series of enactments intended to preserve the country's woods from the encroachments of the ironmasters, was issued in the second half of the sixteenth century. None of them however proved completely effective. One reason was that the iron industry in the Weald of Kent, Surrey, and Sussex was again and again exempted. Even from the enactment of 1558 which seems to have been better observed than any of the others, the Weald of Kent, the county of Sussex, and certain parishes in Surrey were exempted. The enactment prohibited the use for iron-making of timber trees of one foot square 'at the stub' and growing within fourteen miles of the sea or any navigable river.\(^1\) Applications for exemption coming from other parts of the country were almost invariably granted.

Another legislative measure was much more effective. In an Act of 1543 stringent rules concerning coppice woods were laid down. It was ordered that twelve standels or storers per acre in coppices or underwoods of twenty-four years' growth or less should be excluded from felling, and twelve 'great trees' on every acre above twenty-four years' growth. It was also enacted that all coppices or underwoods should be enclosed for periods of from four to seven years after felling. These periods were increased by two years more in 1571.\(^2\) The Enactment only ratified and enforced a state which was no novelty. As early as 1538 the felling of oaks in the woods of Derwent Valley in Cumberland had been stopped, because the purchasers of the timber had 'neyther copyshed nor staddled the same to the great dysstruccon of the said woodes'.\(^3\)

In the year of 1541 in which the bloomsmithy at Rievaulx in Yorkshire was reconstructed and equipped with a water hammer, twenty plots of woodland were marked out, each large enough to supply wood for charcoal to keep the works going for a year, so that by rotation in felling a wood supply was secured for twenty years.\(^4\)

The above two instances taken from different regions indicate that the enactment of 1543 legalised and made obligatory a practice which already existed to some extent, and by so doing gradually enforced its general acceptance. Not much resistance was to be expected from the ironmasters who were aware of the advantages of conserving wood. The result was that by the middle of the century the establishment of coppices had proceeded very well in the area of the Wealden iron industry. Of approximately 6500 acres of wood felled in the parish of Cranbrook in Kent and seven adjacent parishes between 1553 and 1573, nearly two-thirds were coppices. Ironmasters such as Christopher Darell, in

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\(^3\) PRO, Rentals and Surveys, General Series, Roll 959.
\(^4\) Be., Misc. MSS, No. 106.
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Surrey, and Sir John Pelham in Sussex, were noted for the care they took of their coppices. The expansion of the charcoal blast furnace from the Weald into other regions was followed immediately by the establishment of coppices.

In the following century, in which the shortage of fuel increased on account of the boom commencing after 1603, the iron industry had to rely more and more on wood from coppices, so that by the middle of the century coppicing had become almost universal in Britain. The extension of the total area in which coppice wood grew, had a double effect. Firstly it counteracted the shortage of fuel caused by the gradual deforestation of the country, and so ensured the survival of the charcoal iron industry, and secondly, the quality of charcoal improved, as the young wood growing in coppices was more suitable for producing a high-quality charcoal than the wood of old trees.

SEASONING AND COALING OF WOOD

Before the wood was converted into charcoal it had to be seasoned. The method applied for seasoning is described by Evelyn in 1664 as follows: The wood was stacked at 'an airy place (yet out of the Wind, or Sun) and not standing upright, but lying along one piece upon another interposing some short blocks between them, to preserve them from a certain mouldiness which they usually contract while they sweat'. The minimum period of seasoning in which the wood sweated out its sap and became more compact, was half a year.

The first English description of charcoal making or 'coaling' was

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1 Straker, pp. 123 and 125.
2 At the erection of the ironworks near Cleobury Mortimer, in Shropshire, about 1576, half of the 400 acres stocked with oak trees in Wyre forest were enclosed (de novo inclusus) as coppice wood, Longleat, Dudley Papers, vol. xvi, fol. 23v and vol. xx, fol. 43 — Lord Paget's ironworks in Cannock Chase had coppices covering 100, 180, and 200 acres each, PRO, Exchequer KR, Miscellaneous Books, vol. 41, fols. 209v and 49.
3 In the 1620's, e.g., about 3,000 acres of coppices were within a radius of 12 miles around Hereford, BM, Add. MS 11,052, fol. 75 — Coppices for the Earl of Cock's ironworks in Ireland in 1626, Grosart, first series, vol. ii, p. 177 — Around 1660, the extension of coppice woods in the Weald of Kent, Surrey, and Sussex was estimated at more than 200,000 acres, Sussex AC, vol. xxxii, p. 25. In 1665, Yarranton (p. 163) stated that for the iron industry in the Forest of Dean and in Wyre Forest (Shropshire) 'many thousand of acres of coppices' had been planted.
4 A growth of 16 to 17 years was the average in England between 1600 and 1800 (J. Evelyn, Sylva, p. 71. London, 1664; H. C. B. Mynors, 'Iron Manufacture under Charles II', Tr. of the Woolhope Naturalists Field Club, vol. 34, p. 2. Hereford, 1953; J. B. Blakewows, 'Notes on Kinlet', Tr. of the Shropshire Archaeological and Natural History Society, third series, vol. viii, p. 88 (see also App. XVI); in the Forest of Dean it was 14 years as a minimum and 20 as a maximum in 1662, BM Harlean, MS 6899, fol. 335. It shows that the time of preservation had decreased considerably since the dissolution of the monasteries (Evelyn, loc. cit., p. 71), and shortly afterwards (see above note 4, p. 221).
5 Evelyn, loc. cit., p. 95 — In 1679 witnesses testified that the wood 'ought to lye half a year to season it, and that it does usually lye soe long in other places, and should lye longer', PRO, Exchequer Depositions by Commission, 20 Chas. II, Trinity 2.

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given by John Evelyn in 1664.1 It was performed as follows: A piece of ground mostly between 20 and 30 feet in diameter was levelled. This was called the hearth or pit. In the centre a pole was erected around which the logs of wood were laid, some horizontally and others sloping outwards from the centre, so as to form a flattened cone. The object was to obtain a free circulation of air from under the heap to communicate with a central chimney formed by withdrawing the central pole.

Fig. 25. Charcoal making.
From John Evelyn, Sylva, p. 103, London, 1664

The heap was covered outside with layers of small brushwood and turf, and also sometimes with earth on the outside. With the handle of a rake vent holes were pierced through the outer layer. When the heap was sufficiently fired the top opening, including the aperture of the chimney, was closed with pieces of turf. As the fire tended to spread most rapidly at the side facing the wind, a kind of protective screen 8 to 9 feet high was made from hurdles of brushwood.2 The main work of the charcoal-burner was to see that the fire spread evenly through

1 Evelyn, loc. cit., pp. 100–103; reprinted Straker, pp. 132–139 — The article on 'Charcoal' in Dictionarium Rusticum and Urbanicum, London, 1704, is almost verbally taken from Evelyn's Sylva.

2 1542, Panningsride, Sussex, 'VIII brawne hurdelles to defende the wynde from the colepytte', Pe., No. 373 — 1579, Chingley furnace, Goudhurst, Kent, 'to dig & take cover & earth for the colepittes . . . and take small bushes and bowes . . . for the lew [i.e., shelter, a Sussex term] of their colepittes', CRO, Leues, Dyke-Hutton Collection.

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the whole heap, and to stop it by closing the vents as soon as the wood was coaled sufficiently. The time for closing the vents occurred when the smoke ceased to escape through the vent holes. The fire was never allowed to burn too fast, because the quality of the charcoal was the better the slower the coaling proceeded. For this reason, the collier took constant care to keep the covering of earth in good order. If, however, the fire burnt too slowly, he could accelerate the process by opening a new hole in the covering at that part which required more fire. The method described by Evelyn is completely in conformity with the best principles of charcoal burning, and had already been practised for many centuries both in Britain and abroad.

The various manipulations described above required much skill. A good 'collier' was a valuable asset to an ironworks, as the produce of furnace and forge largely depended on the quality of charcoal. Accordingly good colliers were much in demand. In the early days of the blast furnace at various places in Sussex colliers were employed who had come from France in the company of French founders and forgemen.¹

The charcoal delivered at the ironworks was left for at least twenty-four hours in the yard before it was stacked in the coalhouse. This was a precautionary measure to prevent fire, as it happened frequently that coal began to burn again even several days after it had been removed from the coalpits. For this reason, the coals were constantly watched by a fireguard.² The 'dressing' of coals frequently referred to in accounts, consisted in separating the larger pieces of coal from the small and from the dust by riddling with a sieve. Only the larger pieces were considered suitable for the smelting process.

PEAT

Growing shortage of wood for charcoal induced the ironmasters to look for a substitute. Peat and mineral coal were the two sorts of fuel they regarded as an alternative to charcoal in the sixteenth century. Of the two the less suitable for the blast furnace—which required a much higher temperature for smelting than the bloomery—was peat, because of its low calorific value. An early trial was made with peat, dug on the moors of Dartmoor and Exmoor, in Devonshire. In 1550 one Michael Wynston obtained a patent for erecting furnaces and forges for the

¹ Geoffrey Totan, collier at Robertsbridge from 1542-43, born in Normandy, came to England in 1536, Sussex AG, vol. ixxii, p. 260. The collier Peter, a Frenchman, was 'cruelly murdered' in the Forest of St. Leonards, Sussex Record Society, vol. xxi, p. 310. Another Frenchman, the collier John Gybrig, was buried at Fetching (Parish Registers) in 1561—A trial with four cords of wood to find out whether it would produce charcoal of good quality for Middleton furnace (Warwickshire) was made by two colliers in 1592, Middleton Papers.
² At Rievaulx, e.g., in 1603 and 1624, Be., Nos. 431 and 396; in 1637, labourers 'that quenched the furnis coale heape' were given ale, ibid., 537.
manufacture of iron and steel with ‘moor coal’. There is no evidence of any success achieved by this attempt. As peat charcoal was to be used without the expenditure of any wood charcoal, Wynston’s attempt was bound to fail. By the end of the century however peat as a fuel for ironworking was no longer uncommon in England. In the furnace accounts of Rievaulx expenses for the digging, air-drying and carrying of peat to the furnace were a frequent item from 1603 onwards.

The methods used to obtain peat were quite simple and inexpensive. It was dug out of the moor in pieces about one foot square and then left on the ground at a dry spot to lose some of its moisture. Afterwards five or six such pieces were stacked in the open air with one end on the ground for the final drying. This stacking in piles was termed ‘rooking’. When completely dry the peat was carried to the ironworks and stored in a ‘peathouse’.

As peat was very cheap compared with charcoal, public opinion was much in favour of using it in the blast furnace. In the beginning of the seventeenth century there were still some doubts whether the results hoped for would be realised, until the preparation of peat for the furnace was ‘brought to farre better perfection’. It is not known whether any improvements were achieved. Nevertheless, the hopes reposed in the use of peat for iron smelting rose even higher in the latter part of the century. John Sturdie in a letter of 1675 went as far as to declare that by adding peat to charcoal instead of using charcoal alone the quality of the iron was improved. This opinion however was very much at variance with the practical results. At Leighton furnace in Lancashire, where peat was used extensively, the iron produced with a mixture of peat and charcoal turned out to be of poor quality and sold at a much lower rate than the iron smelted with charcoal alone at Backbarrow furnace which was not far distant and worked by the same company. Occasionally considerable quantities of iron produced at Leighton with peat added to the charcoal, had to be re-smelted.

In view of the poor practical results and the failure of prospectors who claimed they could make iron by using peat added to the fuel, or even peat alone, faith in the value of peat as a substitute for charcoal

3 Owen, loc. cit., p. 92–93 — In 1507, ‘gravying, leying, pilling’ [i.e. piling in stacks] is referred to in accounts of the smithy at Treeton, Yorkshire. Oxford, Bodleian Library — Cf. also Boate, p. 154 (for Ireland, in 1645).
4 Phil. Tr., vol. xvii, p. 696 (iron made ‘much better than heretofore’).
5 In the winter campaign of 1715–16 the ratio of peat to charcoal was approximately 1 to 3, Barrow-in-Furness, Public Library, Rawlinson MS, No. 188 — Fell, p. 293 — Swedenborg, p. 156, referred to the detrimental effect of sulphur upon the iron smelted with a mixture of peat and charcoal in Lancashire.
6 The numerous applicants for patents who claimed they could make iron with a substitute
declined considerably in the late eighteenth century. Around 1788 the opinion prevailed that peat had proved 'to answer tolerably well' only, and the use of peat for iron-making was spoken of as something belonging to the past.¹

MINERAL COAL

Peat as an alternative to charcoal proved to be useless, but attempts to substitute mineral coal, after a long succession of trials and failures, led to final success. Very shortly after the establishment of blast furnaces in the coalfields of the Midlands and the north, the idea of utilising the tremendous resources of mineral coal occurred to the ironmasters. The first attempts were made around 1590, almost simultaneously at furnace and forge. At first success was only achieved at the forge. Even there it was no more than a partial success, confined to the last stage of producing malleable iron.

Almost up to 1590 the process of ironmaking at the forge was conducted exclusively with charcoal, apart from one small exception. For repairing their tools the workmen applied mineral coal which required only small quantities.² Larger quantities such as the twenty-three loads from Handsworth coalpit near Sheffield, in 1585, and further twenty loads in the next year, all delivered to 'the hammermen', indicate a use much beyond that for repairing of tools.³ The forge was probably at Attercliffe. The first definite reference to mineral coal for the manufacture of iron is in a letter of 1592, in which the clerk of Sir Francis Willoughby's ironworks at Oakamoor in Staffordshire reported that he had been told by ironworkers of a forge 'they are proposed to make iron with sea cole at the chafery which if they do, will hardly sell above £10 the tonne'. The forge referred to was apparently Harthey forge in the parish of Ripley, Derbyshire, as mineral coal was 'employed for the making of iron' at this forge at about the same time. The reference to a selling price lower than the average implied some doubts about the possibility of successfully forging bar iron with mineral coal. In any case, the attempt was regarded as a novelty by the writer of the letter.⁴

The use of mineral coal in the manufacture of bar or wrought iron was for charcoal were mostly referring to peat, see below p. 227. Some considered peat alone sufficient as a fuel, e.g. Edward Ball in 1630 (Patent No. 51), and Sir Nicholas Slanning in 1673 (Cal. SPD, 1st March to 31st October 1673, p. 201. London, 1901).

² In 1578, e.g. at Rievaulx, 9d. was paid 'for sea coles to the workmen at the forge for mendynge their tolls with', Be., No. 527. By the price, the quantity was half a load — See also Plate xv which shows workmen repairing their tools on an anvil.
³ The Duke of Norfolk's Estates Office, Sheffield.
⁴ For the following see H. R. Schubert, 'Early Use of Mineral Coal in the Chafery of the English Forge', J6., vol. 172, Part 3, pp. 313-314 — About the same time, according to an undated note written by Willoughby, he intended to use 'Mr. Worley's hammermill' which was Holford Mill on the river Tame north of Ashton Hall, Birmingham, owned by John Whyrley in 1591 (Birmingham Reference Library, No. 276768) for 'stringing' of a ton of iron with mineral coal; 'stringing' means elongating by hammering. Middleton Papers.

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confined to the chafery which served for reheating the half-finished bar before it was forged and drawn out by the power hammer into the final shape. Probably this is the grain of truth in the constantly repeated claims of the various applicants for patents in the seventeenth century, including Dud Dudley, that they could make bar iron with mineral coal.

By 1700, the use of mineral coal at the chafery appeared to have gone beyond the experimental stage, but it was not yet general throughout the country. In south Yorkshire it was given up after a few unsuccessful trials in the forges. On the other hand, ironmasters in south Wales and Monmouthshire had no misgivings. In 1704 John Hanbury, who owned furnaces and forges at and around Pontypool and in the Clydach valley, expressed the opinion that when all the charcoal was spent at the furnace and the fineries, iron can be drawn out 'very well with stone coal'. After this date the use of mineral coal in the chafery became more general. In the finery, however, charcoal remained the fuel in the eighteenth century, until Cort's inventions of puddling and rolling, patented in 1783–84, made it possible to apply mineral coal.

The first attempt to use mineral coal in the process of smelting iron was made in Yorkshire, by Thomas Proctor who in 1589 obtained a patent to smelt iron and lead. Proctor, however, did not intend to use mineral coal alone but admixed with peat and charcoal, claiming that in this way 75% of the charcoal used in the smelting process could be saved. Proctor who owned a bloomsmithy at Shipley, east of Bradford, and erected a furnace with a forge in the vicinity in 1590, did not succeed in any way.¹ The idea however was not abandoned. A few years after Proctor's failure, the Countess of Cumberland, who owned a furnace in the district of Knaresborough Forest, sought a licence to smelt iron with a mixture of mineral coal and peat in 1595, and at the same time Sir Robert Cecil, the son of Elizabeth's Chancellor, began to take an interest in the problem. Attempts to smelt iron with mineral coal became more frequent in the following century.² All those who obtained patents claimed to be the first successful inventors of the process of smelting and forging iron with mineral coal, which implied that all preceding attempts had failed.

One important result emerged from all these attempts, the introduction of the reverberatory furnace charged with mineral coal. This furnace was divided into two parts, one for smelting the ore, the other for the coal which produced the heat. The ore did not come into direct contact with the coals but was smelted by the flames emerging from them. The idea was first conceived and published by John


² A survey of the various attempts and patents is supplied by Ashton, pp. 10–12.
Robinson (or Rovinson) of Westminster in 1613. He distinguished between ordinary furnaces, and ‘furnaces of division’ in which the metal was not in direct contact with the fuel so that ‘only the heat and flame thereof can touch the metall’. The new device was immediately taken up by Edward Lord Dudley who owned blast furnaces and forges in the vicinity of Dudley, in the Black Country of Staffordshire. In 1618 he made a contract with Robinson which gave him for a limited period the use of a patent granted to Robinson in 1613 to produce iron with mineral coal over a period of thirty-one years. In the contract of 1618 Lord Dudley not only asserted that he was the one who had paid for Robinson’s previous trials, but also that the ‘newe invencion’ of smelting with mineral coal had been imparted by him to Robinson. The purpose of the contract was, further, to ‘perfect the same worke and invencion’ at Lord Dudley’s expense and to pay to Robinson four shillings from each ton of iron produced with mineral coal alone, and one shilling per ton for iron produced with an admixture of charcoal. Apparently Lord Dudley had first given financial assistance to Robinson and then, realising the tremendous possibilities, had secured for himself the right to use the new method under Robinson’s patent for further trials. It is however not on record whether these were successful, though the idea of smelting with mineral coal was used immediately afterwards by Lord Dudley’s illegitimate son Dud Dudley. It is not impossible that he made use of experience gained in the trials of 1618. According to claims which he later published in a book, he appears to have gone one step farther by applying the method of smelting with mineral coal to blast furnaces in 1619.

Dud Dudley’s claims to have succeeded where all others had failed, are generally rejected even by contemporaries. There is however a possibility which would justify his claims to a limited extent. It is not impossible that he hit on a vein of hard splint coal strong enough to hold up the burden in a contemporary furnace the height of which did not exceed thirty feet. Splint coal, however, was rare, and by his own statement he produced not more than three tons of iron per week at first, and later seven tons which is one ton in twenty-four hours. At a time at which the weekly production of pig iron was from two to three times as high, Dud Dudley’s production could not be accepted as a success and the contemporary ironmasters did not, as he asserted, act out of envy or spite when they rejected his claims and proclaimed that he was unable to produce ‘merchantable’ iron which could hold its

4 M. Davies, The Story of Steel, p. 18.
place on the market. Any ironworks with a production as small as that reported by Dud Dudley would have been condemned as an economic failure within a short period.

There was only one way to make full use of the tremendous resources of mineral coal within the country, and that was coking. Nothing in Dud Dudley's book is indicative of any attempts on his part to produce coke first. The idea of eliminating the sulphur detrimental to iron by coking the raw coal occurred to ironmasters as early as the first attempts at applying mineral coal. Almost a century later, however, it still was regarded as impossible to produce coke suitable for the smelting process. It was reserved for the Darbys at Coalbrookdale to be the first who successfully smelted iron with coke obtained from mineral coal in the early eighteenth century.

**FLUXES**

The addition of fluxes to promote the formation of slag was of great importance. Not only was the quality of the iron improved but the amount of fuel required for smelting depended upon the flux to a considerable extent.

The fluxes used in Britain were limestone, and slags left from old bloomeries. Slags, or cinders, from old bloomeries were added in the Forest of Dean where they were found in enormous quantities as refuse from the iron-working of about 1¼ millennia. The ratio used from the seventeenth to the nineteenth century was half slag and half ore. Old bloomery slag was exported in the first half of the seventeenth century in large quantities from the Forest to Ireland, mainly to the Earl of Cork's ironworks in the south. Other furnaces used limestone as a flux.

There was, however, one other flux, which was used only in Sussex where it was found in the ground. This was a layer of shells concreted with iron ore and termed 'greys'. In the eighteenth century it was used as a fluxing agent in the furnace at Robertsbridge and in another furnace within a few miles of Tunbridge Wells, probably Barden furnace. This flux had a very beneficial effect upon the iron which turned out to be 'always a fine, genuine, good sort of metal; possessed of every good quality, that can be desired'.

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2. A. Fuller, *Part II*, p. 97 (quoted by Straker, p. 129), in 1662: 'seems impossible in this generation' — J. Pettus, *Fleta Minor*, and part, p. 84, London, 1683, referring to the many attempts made added, 'but I have not yet heard of any certain success therein (though I wish it)'. See also Plot, p. 128 (in 1686).
3. See below Chapter 19.
4. *Necro. Tr.*, vol. vi, p. 45 — At Park furnace in the campaigns of 1656-57 and 1666 one ton of slag was added to the charge to one of ore, PRO, SPD, *Navy Papers*, vol. 1578, and *Exchequer Special Commissions*, No. 6080.
CHAPTER XIV

THE SMELTING PROCESS

EARLY LITERATURE ON THE PROCESS

Two spectacles associated with smelting at the blast furnace impressed the early writers on iron-making more than anything else: the torrent of liquid iron that from time to time gushed forth from the hole at the bottom of the furnace, and the flames rising from the open top aperture high into the sky.

The tapping of the molten metal was the great moment which always fascinated spectators and stirred their imagination. That commingling of classical mythology and Christian ideas so characteristic of the Renaissance period, led the Italian architect Filarete when he visited a furnace in the Italian Alps north of Piacenza around 1470 to say of the founders working the liquefying mass in the hearth with iron staves and tapping it, that they reminded him of those fellows who tormented the souls in the house of Pluto. Nicolaus Bourbon in his poem of 1517 compared the mass of liquid iron which ran out of the tap hole to the eruption of a volcano.¹

Gerard Boate, who wrote in 1645, said of the flames from the gases escaping from the open top of the furnace that they 'may be seen a great way off in the night, and in the midst of the darkness maketh a terrible shew to travellers, who do not know what it is'.² Thomas Baskerville who travelled from Ross to Gloucester in 1682 and saw a furnace near Longhope mentions that 'the flame mounts fiercely a good height above the furnace'.³

The smelting process and the various operations involved began to attract English writers in the seventeenth century. The first was Gerard

¹ Antonio Averlino Filarete's 'Tractat über die Baukunst', edited by W. von Ottingen, Quellenzfriften für Kunstgeschichte, Neue Folge, III Band, p. 473. Wien, 1890 — Bourbon's poem called 'Ferraria', i.e. the Ironworks, was published at the end of his collection of poems called *Nagae*. Paris, 1533. — Straker, pp. 41-43; published a translation into English based on a French translation.
² Boate, p. 131.
Boate, who obtained his knowledge from English ironmasters in Ireland. Ray, Powle, and Plot wrote on iron-making in various regions of England in which the iron industry held a prominent place in public economy, such as the Weald in the south-east, the Forest of Dean in Gloucestershire, and Staffordshire in the Midlands. None of these four writers, however, was an ironmaster, so that their knowledge was but second-hand. This is reflected in their reports, inasmuch as more attention is paid to preliminaries and accessories such as the preparation of materials and furnace before smelting commenced, the casting of the pigs in the sand bed at the end of the process, and the working of the bellows. The process itself is rather briefly dealt with which, however, is not really surprising, as the knowledge of it was based only on practical experience passed on from one generation of founders to another and kept secret from outsiders. The only one of these writers who appears to have penetrated a little more into the nature of the process was Powle. Probably this was recognised and appreciated in his days and afterwards, since it was his account of iron-making which was mostly reprinted in the various English encyclopaedias of the early eighteenth century, and less often those written by Ray and Plot. Even in a description of furnace and process in Lancashire in the early eighteenth century the author has drawn copiously upon Powle.

Interest in the subject increased in the later part of the eighteenth century, mainly on account of the works of Swedenborg (1734) and the extensive literature on iron-making in France commencing with Réaumur (1722). The wider interest induced Dr. Lewis, F.R.S., to compose his manuscript-history of iron which was left unfinished at his death in 1781. This work mainly contains abstracts from French, German, and Swedish writers on the subject, but it also contains some valuable contributions by two Yorkshire ironmasters: Pashley, and John Cockshutt, senior, who died about 1765. The English treatises and tracts published towards the end of the century became more explicit and more independent of Powle.

1 Boate, pp. 131-132, 138-140. App. XIV.
2 Cf. Appendices XIV and XVII.
3 See Gille, pp. 85-91.
6 Most of the contributions were made by John G. senior who also published a treatise on iron-making in The London Magazine, vol. xxxi, pp. 67–69. London, 1752, under the pseudonym of Britannisus. Some later contributions were made by his son John, of Worley and of Seamer forge near Scarborough. Pashley was a friend of both, but very little is known of him.

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With the help of this early literature, supplemented by evidence from documentary sources, it is possible to reconstruct the process of smelting, as it was conducted in the seventeenth and eighteenth centuries. It is more difficult for the preceding sixteenth, but the construction of the furnace and the various implements employed in smelting, the use of which is documented frequently in early accounts and inventories, point to a close similarity. On the whole, the process remained the same. In essentials it conforms to the process conducted in a modern blast furnace.

PREPARATION OF CHARGE AND FURNACE

A proper composition of the charge and a well-heated furnace were preliminary conditions, upon which much of the success of the smelting operation depended.

The proportion of coal charged was based upon the quality of the charcoal, but also upon the quality of the ore. For the casting of cannon, however, the ratio of charcoal to ore was much greater than for producing pig iron.

Slags or cinders from old bloomeries were added to the charge in various regions, principally in Gloucestershire in the furnaces of the Forest of Dean from the time of their first erection to the end of the eighteenth century, but also in Lancashire and in Ireland (imported from Gloucestershire). In the Forest of Dean the proportion was nearly one-half of the furnace burden. Slags were found highly advantageous when mixed with the calcareous ores of the district.

The average ratio of limestone as a fluxing agent was one basket to ten of ore as a minimum and one to twenty as a maximum. The richer the ore was in iron contents, the less flux was required, since ores abounding in metal contained smaller quantities of earth which required fluxing. The clay ironstones of the coal measures required no flux, or

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1 H. Horne, a prominent English metallurgist, wrote in 1773 (Essays concerning Iron and Steel, pp. 54–55) that he had visited several furnaces, particularly in Staffordshire, Yorkshire and Sussex, and had found 'their methods of working nearly the same'.

2 Robert Plant, clerk of Lizard forge in Shropshire, testified in 1659 that he was 'told by founders and workmen that a ton of iron can be melted with 2 cart loads and 2 bags of good coal, but ... with bad coal not under 3 cart loads', PRO, Exchequer Depositions by Commission, 1650, Easter 4. In the furnaces of the Forest of Dean 14 tons of charcoal were consumed in the production of each ton of pig iron from 1626 to 1683; and, presumably, throughout the whole period of furnace production in the Forest, Rhyg Jenkins in Nwec. Tr., vol. vi, p. 50.

3 In the Forest of Dean 12 cords of wood were required for pig iron, but 22 cords for ordnance in the early seventeenth century, BM, Harleian MS 7009, fol. 16.


5 Lewis, vol. iv, p. 88v; vol. v, p. 31. In Lancashire the ratio of flux to ore was 1 to 17 in 1675, Phil. Tr., vol. xvii, p. 696, which was also the ratio at Backbarrow in the campaigns of 1746 to 1755; at Leighton, also in Lancashire, where peat was used in addition to charcoal the ratio was much higher (approx. 1 to 10) from 1715 to 1718 and in 1725, Barrow-in-Furness, Public Library, Rawlinson MS 188.
very little, because the ore contained limestone sufficient to work as a fluxing agent.\(^1\)

Since different temperatures were necessary for the smelting of different ores, the ores were mixed, so that a medium temperature should be generated which ensured a good working of the furnace. There is ample evidence that the advantages of mixing were known to the sixteenth-century ironmasters. The stocks of different ores, e.g. those accumulated for the furnaces in Cannockwood, Staffordshire, clearly indicate that high grade ores from Walsall, the richest in the county, were employed together with the leaner local ores.\(^2\) The advantage of ore-mixing was known even outside the class of professional ironmasters and founders. In 1620 a Bristol merchant recommended it to Richard Boyle as the proper way of amending the hardness of his Irish iron.\(^3\) Judging by statements made by seventeenth-century writers the practice was completely general in Britain at least in the latter half of the century.\(^4\)

The value of scrap iron added to the charge for improving the quality of iron was also known at an early date. Scrap of wrought iron which had already been refined contributed to the dilution of impurities in the pig iron to be produced. The beneficial effect of scrap was known in Yorkshire as early as in the sixteenth century. At a trial made at Shipley near Bradford, in 1591, it was suspected that pieces of a wrought iron bar, which served for stirring the melting matter, were knocked off into the mass, to obtain a better iron from the ore. Scrapes were bought for Parkend furnace in the Forest of Dean, to be added to the charge in the campaign of 1656 to 1657, and for Robertsbridge furnace, Sussex, in 1701.\(^5\)

The earliest evidence for the use of hammer-slag from the forge in the smelting process is of 1605.\(^6\) By the end of the seventeenth century the practice of adding hammer-slag to the charge was adopted in Gloucestershire, Monmouthshire and south Wales. In the Midlands slags obtained from the forges were added to the charge in the eighteenth century, so as to improve the quality of the iron which, if produced

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1 At Wortley, Yorkshire, generally no flux was used; Lewis, Knights, vol. iv, p. 89 — at the furnaces of the Knights extending from Briggwood, Shropshire, to Aston, in Birmingham, the average proportion of flux was in the eighteenth century about \(\frac{1}{10}\) or \(\frac{1}{10}\) of the weight of ore, Lewis, Knights, p. 77.

2 Stafford, Wm. Salt Library, D. 1734, and PRO, Eschequer Various Accounts, Bundle 546, No. 16 — At Middleton, in 1592, seven boxes of Walsall ore and three of leaner ore from Grendon, in Warwickshire, Middleton Papers.

3 Cork MS, vol. 10, No. 91.

4 App. XIV (Weald); Plot, p. 161 (Midlands); Phil. Tr., vol. 17, p. 196 (Lancashire); Boate, pp. 136-137 (Ireland). For Scotland see PSAS, vol. xxi, pp. 122-124.

5 PRO, Eschequer Depositions by Commission, 35/36 Eliz., Mich. 34: 'cut off sundrie pieces', and 'They would put something in and then they would doe well enough.' — For Parkend see PRO, SF, Interregnum, No. 1578 — 'Broken gun mettall and other scrap iron' bought from Hawkhurst furnace, Penhurst Place.

6 At Rievaulx, 'leading 6 lo(des) of hamslowe from the forge to the furnace', Be., No. 881.

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from the ores alone, might have turned out to be 'cold-short' (brittle when cold), and thus unfit for common use.¹

Before the charge was fed into the furnace, the interior had to be well heated in order to get rid of all moisture which might evaporate from the walls. This was termed 'seasoning the furnace'. It was particularly necessary because of the open top aperture through which rain and snow might fall. Devices such as thatching, i.e. covering the top aperture with reeds and straw in between the campaigns (periods of blowing) were not sufficient to exclude all moisture. If the interval between two campaigns extended over a considerable period, as often happened, the effect of moisture could be disastrous. At Llanelly, in Breconshire, the furnace which had been idle for more than two years from 1702 to 1704, was 'almost ruined for want of being covered'. To prevent a repetition it was proposed to build a brick cupola with large doors over the top aperture, and also to keep a constant fire in the hearth of the furnace during the whole period in which the furnace stood idle.² According to the available evidence the preliminary heating took from three to eight days, mostly from three to four.³ The fuel used was charcoal, sometimes with an admixture of peat, or, very frequently, of mineral coal.

CHARGING AND 'BLOWING-IN'

As soon as the founder was well satisfied that the masonry of the interior was perfectly dry, the charge was built up. First a grate was constructed by laying short iron bars across the hearth from the open front aperture to the back wall. The grate, which rested on bricks, supported the fuel which was gradually filled in with a small amount of ore on the top. Underneath the grate an empty space was left by which draught and heat were considerably increased.⁴

During all the time in which the filling went on, the fire was kept burning. When the first drops of molten iron were observed trickling down in front of the tuyere hole, the time had come for laying the damstone, well embedded in clay. The grate was withdrawn and the burden tumbled down into the hearth. The tap hole at the side of the damstone was closed by a stopper of clay mixed with sand. To close the

¹ In the winter campaign of 1699-1700 conducted at Redbrook furnace in the Forest of Dean, 64 dozen 8 bushels of 'hamilaw' were spent, CRO, Gloucester, D. 421/E9 — Forge cinders were used at Pontypool and Llanelly furnaces with good results in 1704, App. XVI — For the Midlands see Lewis, Knights, p. 77.
² App. XVI.
³ In south Yorkshire pre-heating the furnace took three to four days between 1698 and 1726 (Rastrick, in Nene, Tr., vol. xix, p. 67) which is about the average in England; at Heathfield, Sussex, three days in 1740, Sussex AC, vol. lxvii, p. 32. See also Plot, p. 161 (Staffordshire).
⁴ The empty space is the 'hollow at the bottom', referred to by Powle in 1678 (see App. XIV) — At Bersham, Denbighshire, a mason was employed for 'building the charge' in 1726, Kelsall.
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gap between the top of the damstone and the bottom of the timpstone, hot coals were drawn towards the dam and covered first with moistened coal dust. On this a mixture of earth and slag was laid and on top of it a small amount of earth or sand. This cover, however, was not absolutely tight, so that a few cracks always occurred through which a little flame and smoke escaped. If small, they were ignored as of no consequence, but if they grew too large, moistened earth or sand was thrown upon them. 1

To make the cover completely tight, an iron plate was sometimes placed between timp and damstone. 2 This, however, does not seem to have been the rule everywhere, perhaps because it caused some inconvenience through having to be withdrawn each time the surplus of slag was let out.

When everything was ready the nozzles of the bellows were put into the tuyere and the blast was turned on. The position of the tuyere was of great importance, for if it were too low the blast would not act sufficiently on the coals; if too high, the most intense heat would be generated in a zone too remote from that part of the hearth in which the ore was in fusion. 3

The ‘blowing-in’ of the furnace was a great event and a cause for celebration, for which bread and ale were allocated to the furnace workers at the expense of the management. 4

Blowing started with a gentle blast which was gradually increased. It had to be gentle at first in order to avoid cracking the masonry by the unequal expansion of such a large mass liable to occur if heat was urged too rapidly at the start.

The charges were small to begin with, so that the working of the furnace could more easily be observed. If all went well they were gradually increased. The filler who was responsible for the charge measured the degree of subsidence with a ‘gage’, an implement which looked like a flail. 5

1 Lewis, vol. iv, p. 147 — Water for moistening was taken from a trough which also served for cooling the implements, see below Plate xx. It is referred to in the furnace book of Pamplingridge of 1556 as ‘a newe trofe for the fornes’, Pe., No. 982/7 — ‘leading of cole dust from the forge to the furnace’ at Rievaulx in 1603, Be., No. 588.

2 Boate (1645), pp. 128–129: ‘they unstopp the Hearth and open the mouth thereof (or the Timpas the Arts-men call it) taking away a little door of fashion like unto that of a haker’s oven, wherewith the same was shut up very close’.

3 Lewis, vol. iv, p. 116. In the eighteenth-century furnaces in the vicinity of Barnsley, Yorkshire, the tuyere was ‘placed a little sloping, at an angle of perhaps three degrees’, ibid. (statement by John Cockshutt). The importance of the position of tuyere and bellows was recognised in the seventeenth century, which is indicated by Plot’s remark on the ‘ordering’ of the bellows being not ‘of less concern’, App. XIV.

4 Pantologia, loc. cit., vol. vi — App. XIV (Ray, in 1674) — Bread and ale for furnace workers at Rievaulx in 1551, Be., No. 529.

5 The part answering to the beater of the flail was of iron (2½ feet long), fastened to the wooden handle with an iron ring. Gages are mentioned frequently in inventories, e.g. in 1635, App. XII. Working with a gage is shown in Plate xvm. By a letter from Lancashire, the furnace was filled up again when the charge had subsided to ‘about a yard and ¼’, Phil. Tr., vol. xvii, p. 696.

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SMELTING

The smelting of iron is based on a chemical change. To put it simply, the carbon of the charcoal combines with the oxygen of the ore (oxide of iron) releasing metallic iron and oxide of carbon, which is illustrated by the following formula:

\[
\text{Oxide of Iron} + \text{Carbon} \rightarrow \text{Iron} + \text{Oxide of Carbon}
\]

(ore) (charcoal) (metal) (gas)

The underlying principle of the process is called the counter-current principle, since two different masses are caused to travel past one another in opposite directions. One is the blast-air introduced through the tuyere in the lowest part of the furnace and ascending as a gaseous current to the top. The other is the charge, the materials of which are fed into the top aperture and descend towards the bottom of the furnace. The interaction between the gaseous blast and the constituents of the charge constitutes the process of smelting.

In the charcoal blast-furnace the reaction of the ascending blast upon the descending ore proceeded in consecutive stages, which correspond to the different zones or horizontal sections of the furnace.

In its descent the ore first entered a zone of preparation, in which it was released from hydroscopic water and also from carbonic acid if the ore was a carbonate.

The second zone was the zone of reduction, in which the oxygen of the ore was taken up by the ascending gas. This left the ore as a mixture of metallic iron and foreign matter reduced in bulk. The first two zones corresponded with the tunnel of the furnace. The process conducted in them was somewhat similar to that of roasting the ore.

The lowest part of the tunnel and the upper part of the third zone, termed the boshes, formed the wider section of the interior of the furnace. The width allowed for the expansion of the materials and their tendency to stick to the sides. Near the top of the boshes the formation of slag commenced, i.e. the earthy parts of the ore united with the lime used as a flux. Carburisation of the iron took place in the region of the boshes. The materials gradually passed from a pasty stage to a more liquid state. The increasing liquidity of the materials in their descent through that region is reflected in the contracted shape of the boshes.

The fourth zone, which was the hearth above the tuyere, was the zone of fusion and combustion, in which liquation of iron and of slag increased, until it was completed in the region of the tuyere where the highest temperature was generated. The liquid iron collected at the bottom of the hearth on account of its higher specific weight while the slag floated on top of the molten metal, but below the level of the tuyere.

Smooth working of the furnace and success of the operation depended
greatly upon the skill of the founder. The importance of his work is significantly expressed in a letter of 30th July 1754, written by John Fuller of Heathfield furnace, to the Prince of San Sorrino, Envoy of the King of Naples and Sicily who intended to order cannon to be cast at Heathfield. Fuller wrote, 'A Furnace is a fickle mistress and must be humoured and her favours not to be depended upon. I have known her produce 12 tons per week, and sometimes but 9 tons, nay, sometimes

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Fig. 26. Zones of the blast furnace.
but 8, the excellency of a Founder is to humour her dispositions, but never to force her inclinations. 1

To observe the smelting process the founder looked into the interior of the furnace through a small open space between the nozzles of the bellows, called the founder’s ‘eye’. 2 Through the hole he was able to observe and to judge the process by the colour and appearance of the metallic drops trickling down from the ore and collecting in the hearth, as well as by the appearance of the slag floating on the surface of the molten mass. Dark-coloured slag and iron indicated that the quantity of fuel in the charge was too small. If through lack of fuel, the temperature fell too low, the iron was not sufficiently reduced and much of it remained in the slag which appeared black and compact and was less fluid than desired. In such a case the iron produced was of a white colour, hard and intermixed with particles of slag, and liable to great loss in forging. If the quantity of fuel was larger and a higher temperature was thus generated, the drops of iron trickling down and also the slag were of a brighter colour. The slag contained less iron and was more liquid. The iron produced was darker, less intermixed with slag, more tenacious, and therefore less fusible and less liable to loss when it was forged.

The state of iron and slag in the hearth could also be ascertained by introducing a long iron implement called a ringer, on which some scales of iron and slag concreted. 3

Careful observation of the various signs enabled the founder to exert some influence in producing the kind of iron desired. This, however, was possible only to a limited extent, since much depended upon the quality of the ore, the height of the furnace, the size of the hearth, and the rate of cooling of the liquid iron when it was cast. In the first of the above-mentioned two cases the iron produced would be white cast iron, so called since the fracture of it is white. The carbon contained in this type of iron is present as cementite which is intensely hard, so that the iron when cast is very hard, but brittle. In the second case the iron produced would be grey cast iron, the fracture of which is grey. The most important constituent of grey cast iron is carbon in an uncombined condition, i.e. in a state of diffusion through the mass, as graphite. It is softer and less brittle than white cast iron. At an intermediate state in which the grey and white kinds are visible in the fracture of the same iron, the cast iron was called mottled iron.

It was also the founder’s business to notice approaching dangers

1 Sussex Ac. vol. lxvii, p. 51.
2 ‘oculus fusoris’, Swedenborg, p. 41 — Nicholson, loc. cit., vol. ii, p. 585 (‘looking into the furnace through the black hole’).
3 After the ringer had been withdrawn, the scales were knocked off with a small hammer, used, e.g. at Rievaulx furnace in 1591 ‘for beating of sunders of the ringers’; it was made of wrought iron at the forge and had a weight of 5½ lb., Be., No. 530. For illustration of ringers see below Fig. 27.
early enough to prevent them. The greatest danger was a partial blockage of the furnace called a 'scaffold'. If ore and flux were not proportioned properly so as to produce a sufficiently liquid slag, or if the proportion of fuel was insufficient to generate a temperature necessary to form and liquify the slag rapidly enough, an agglomerated mass of the materials would be formed, causing a partial blockage. This would seriously interfere with the working of the furnace, by preventing an even distribution of the ascending gases, thus lowering the temperature at the place of the blockage and thickening the agglomerated mass still more. If the materials underneath the scaffold descended, the mass was liable to tumble down suddenly and cause a total stoppage of working. The danger of 'scaffolding' was greatest in the region of the boshes, in which 'hanging' of the materials was facilitated by the viscosity of the slag in that particular zone. Recognition of the danger of scaffolding in the boshes is implied in Powle's description of 1678 in which he referred to the running together of the materials in a hard cake or lump.

As soon as the slag floating on top of the liquid iron reached the top of the dam, the cover which closed the gap between the damstone and the timpstone was pierced to let out the surplus of slag. Larger slag which did not run out easily and pieces of unburnt charcoal were pulled out with iron hooks called 'cinder hooks'. Outside the hearth the slag cooled quickly and became a solid mass which was removed with 'cinder shovels' and 'cinder rakes' to make room for fresh slag.

In the following illustration the most important implements used in

![Figures 1-5 showing implements used in the smelting process.](image)

**Fig. 27.** Implements used in the smelting process.


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1 App. XIV.
2 Boate, p. 138: Two men standing at the slag hole, one at each side, 'with long iron hooks... draw out the unburnt coales, ashes and cinders, which cinders are great lumps of firm substance'.
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the process are depicted. These remained the same throughout the period in which the smelting of iron was carried out in charcoal blast furnaces.

Explanation

(1) Great or long ringer (from French 'ringard', 15 feet long in the eighteenth century). Generally the weight varied between 36 and 44 lb. in the sixteenth and seventeenth centuries, Be. and Pe., passim. Some ringers were heavier: in 1552 two 'great ryngers' were made for the furnace at Panningrige at 62 lb. each, Pe., No. 382(2). Another 'great ringer which the funderer doyth let his sow runne withall' at Rievaulx in 1591 had a weight of 76 lb., Be. 529. The quotation indicates the use of such a ringer; the founder pierced the tapping hole, the length of his implement enabling him to keep clear of the mass violently gushing out of the tap hole into the sand bed in which it formed the sow. The 'constable' referred to in furnace inventories of the Forest of Dean, may have been such a ringer, App. XII.

(2) Ringers of a smaller type (12 feet long), weighing between 27 and 32 lb., Be. and Pe., passim. They were mainly for clearing the hearth.

(3) Hook, or cinder hook (see above p. 239, note 2). The 'crochet of iron' mentioned in the inventory of Newbridge in 1509-10 (App. VI) was such a hook; crochet was the usual term in France.

(4) Tuyere hook, used to clear the tuyere of the slag and particles of iron that tended to adhere to it. It was considerably smaller than 3. It also is mentioned in the Newbridge inventory of 1509-10 (App. VI) as 'a stockarde of iron', the term being derived from French 'stoucar' (Traité du Fer, loc. cit., p. 54).

(5) Placket (from French 'placoire'), a tool designed as a kind of trowel for smoothing and shaping the clay into which the tuyere was fixed. Comp. inventory of Rievaulx furnace 30th October 1578: 'one plackett for dawbing the fornace where the yeron lyethe', Be., No. 527. Inventory of Araglin furnace, County Cork, of 1655: 'plackett to dawb the twire', Cork MS., vol. 28, No. 46.

Most of the implements are referred to in the inventories of the furnaces in the Forest of Dean of 1635, App. XII.

How often the slag had to be removed depended on the quality of the ore, and on the state of the iron collected in the hearth. If the ore was rich, containing little gangue, in particular little calcareous or stony matter, slag was let out not more than four or five times within from seven to ten hours. If however the ore had an abundance of gangue, the slag-hole was kept almost constantly open. Some of the slag was always left as a cover above the liquid mass of iron. By protecting it from the blast, it preserved the heat and the fluidity of the molten metal. The less fluid the iron, the more slag had to be left on it. The cover also
The Smelting Process

protected the iron from contamination by insufficiently reduced matter falling down into it. If that happened the iron became unsuitable for the finery process.¹

When the quantity of the molten iron collected in the hearth was so large that it reached the upper edge of the damstone, the time had come for tapping the liquid mass. The blast was turned off and the founder pierced the clay which closed the tapping hole, with a ringer. On the average, tapping commenced three days after the blowing-in of the furnace, and was repeated once or twice within twenty-four hours.²

The repetition of tapping continued throughout the whole period of blowing termed the campaign, without being interrupted either on Sundays or festival days, which clearly emerges from the account of the winter campaign at Rievaulx in 1591–2. By the same account, the full capacity of 20 cwt. (at one tapping) was not reached earlier than eight weeks after preliminary heating had started. Amounts decreased markedly towards the end of the campaign, as the hearth was worn out by that time.³

The tapped iron ran into a bed of sand carefully selected by the founder who frequently supervised the transport of sand to the furnace. The sand was moistened with water to make it cohere, but not too much; it had to retain sufficient porosity to permit the free escape of the gases generated by the action of the high temperature of the molten iron on the water and organic matter it contained. Otherwise the gases would bubble up through the liquid iron. Further, if the sand was disturbed by the gas released, the hot iron was given access to sand underneath which was wetter still. As a result more gas would be generated and released. This process continued with progressively increased violence, until the pig iron ‘boiled’, which caused loss of metal.⁴

After the sand bed had been laid, the founder made a gutter or furrow with an implement termed a ‘moulding ship’, or ‘moulding shovel’.⁵ In the sixteenth and early seventeenth centuries one furrow for one sow only was made. In the last quarter of the seventeenth century a more elaborate system was introduced which consisted in making one

¹ Lewis, vol. iv, p. 140 — Pigs were left at the furnace of Rievaulx in 1603 and 1605, because they contained a ‘legard’, Be., Nos. 431 and 881.
² John Hill, keeper of the furnace at Whitchurch, Herefordshire, who had been employed ‘at several other like furnaces’, deposited in 1672, that every time the furnace ‘casteth iron which is usually twice every twenty fower howers’, the furnace ‘always ceaseth to blowe during the time of the metall running’. PRO, Exchequer Depositions by Commission, 24 & 25 Chas. II, Hilary 15.
³ App. X. In the winter campaign of 1696–37 the same time elapsed until full capacity was attained, Be., No. 537.
⁴ A ‘boyled sowe’, e.g. was taken from the furnace at Rievaulx to the forge, in 1641, Be., No. 539.
⁵ In 1577, the finer at Rievaulx was paid for making ‘two mouldyng shovells to the founder to occupye at his work at the fornace’, Be., No. 527. The weight of the iron employed in making such shovels or ships varied between 45, 7, and 11 lb., Be., Nos. 527, 530, 535.
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main furrow or channel to receive the sow, and a number of lateral transverse channels of shorter length branching off from the former.  

To prevent the liquid mass from running out too rapidly, the founder used an iron hook called a 'hardew' or 'stopping hook'. When the sow had been cast, some sand was thrown from a shovel over the surface of it, so as to diminish the effect of the heat radiating from the molten metal and also to prevent the iron from being chilled and thus turned into white cast iron instead of grey.

The product obtained was not always of the quality desired by the founder. Occasionally, it happened that an unsmelted residue called a 'bear' collected in the hearth. There were various causes for the formation of a bear, such as pieces of stone detached from the hearth, particularly likely to happen when the hearth was worn out at the end of the campaign; ill-melted slags, or moisture penetrating into the bottom of the furnace and chilling the bottom stone and the molten mass. Another cause of this mishap was known as 'tumbling' of ore in the furnace, i.e. a quantity of hard ore 'getting together' as John Fuller, ironmaster at Heathfield, worded it, 'which will not readily melt, or perhaps not at all, and then falls down in a lump, hard as it is and spoils the other metal in the hearth'. If a bear became too large to extract through the front aperture of the hearth, the furnace had to be blown out.

After each casting the hearth of the furnace had to be cleared with ringers of slag adhering to the walls. This operation, during which the blast was stopped, is depicted by Henri Blès in one of his paintings representing a blast furnace of the early sixteenth century (Pl. XX).

On the right side of the fore hearth an ironworker is seen clearing the interior with a ringer. The dark spot on the left side represents slag adhering to the outside of the fore hearth where it has concreted after running over the damstone. It is a pity that the artist should have placed a water-trough right in front of the wheel.

When the last casting had been finished and the furnace was blown out, the interior required a complete overhauling. The 'new laying' of the hearth by the founder is an item constantly re-occurring in the furnace accounts. The destruction of the interior was not confined to the hearth, but extended higher up to the boshes. Even the inner lining

1 Plot (1686), p. 162: 'they make one larger furrow than the rest which is for the sow, from whence they draw 2 or 3 and 20 (i.e. 22 or 23) others (like the labels of a file in Heraldry) for the pigs'. The difference between a sow and a pig was a difference in weight, see Ray, App. XIV.

2 'one hardyeron', at Rievaulx, in 1578, Be., No. 527. In 1592 it was described as a 'hardewe which the founderer doth stope the sowe withall yt rumme not over fast', weighing 14 lb., Be., No. 529. At Parkend furnace, in 1625: 'dam hooke or stopping hooke', App. XII.

3 'sand to dust the sowe', at Oakamoor furnace, Staffordshire, in 1599, 1605, et seq., Middletem Papers. See also Percy, p. 493.

4 Straker, p. 91 (with a picture of a bear at Beech Mill). A bear weighing approx. 1 ton is on the lawn in front of Hastings Museum. Cf. also Be., No. 529 (1590-1 Rievaulx): 'one sowe which did sinke into the harth and was taken for the furnace bottom'.

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of the tunnel did not remain unaffected, in any case not in its lower part, which joined the boshes. Both founder and filler were frequently engaged in breaking off the slags from the walls. In 1558 it took the founder of Panneringe furnace two whole days to clear the inner walls of slags.¹

**DURATION OF CAMPAIGN, OUTPUT, AND YIELD**

In 1593, Richard Pegg of Shipley near Bradford, Yorkshire, who had been a 'master workman about the making of iron' for twenty years 'in most of the best ironworks in England', stated that a furnace could only yield a profit if it were kept blowing for twenty to thirty weeks within a year.² A blow or campaign of thirty weeks within one year was still considered satisfactory in the seventeenth and eighteenth centuries.³ There is, however, a significant difference in this respect as between the earlier and the later period. Until some years after 1600, several campaigns (from three to four) in the course of one year were the rule, but later one campaign only. Accordingly, the length of the single campaign was much shorter in the earlier period. Compared with the figures of output, details in respect of dates at which blowing commenced and ceased are few, but they suffice to show the general trend.⁴

The longest campaigns were conducted in winter, mainly between

¹ 'workyng within the fornys in betyng downe of the synder there', Pe., No. 382(8). In 1554 the filler was engaged with 'syndering of the phurnaces walles', Pe., No. 377(2).
² 'No man can make any good profit or gayne by any furnace for iron unless there be water enough to keepe the same on worke by XX or XXX weeks', PRO, Eschequer Depositions by Commission, 33/6 Eliz., Mich. 34.
⁴ Robert'sbridge, Sussex, 1541–45, average 14½ weeks, Pe., passim.
Sheffield, Sussex, 1546–49, average approximately 8 weeks (10 blowings), *Arch. J.*, vol. 69, p. 292.
Panneringe, Sussex, 1546–56, average 18 weeks (extremes 5 and 36), Pe., passim.
Oakmoor, Staffordshire, 1593–1608, average 13 weeks (extremes 3 and 22), *Middleton Papers*.
Rievaulx, Yorkshire, 1609–24, average 18½ weeks (extremes 8½ and 21½), Be., passim.
Cannap, Gloucestershire, 1621–24, average 20 weeks, PRO, *Eschequer Special Commissions*, No. 5304.
Lydbrook, Gloucestershire, 1621–26, average 31 weeks (extremes 19 and 49), ibid.
Waldron, Sussex, 1632–35, average 26 weeks, BM, Add. MS, 33154.
Rievaulx, Yorkshire, 1636–31, average 18 weeks, Be., passim.
Waldron, Sussex, 1690–99, average 27 weeks, BM, loc. cit.
Heathfield, Sussex, 1703–06, average 25 weeks, Sussex AC, vol. 1xxvii, p. 27.
South Yorkshire, 1668–1756, average 26 to 30 weeks (extremes 20 and 35), Raistrick, loc. cit. — (Cf. note 3, above).
Blakeney, Gloucestershire, 1692–1704, average 34 weeks
Elmbridge, Gloucestershire, 1692–1709, average 52 weeks
Mearheath, Staffordshire, 1693–1707, average 37 weeks 2 days

Details kindly supplied by B. L. C. Johnson, M.A., Birmingham University.
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September and April. This arrangement was quite general in the later period of blast-furnace production, in which not more than one campaign took place in the course of a year. It afforded the advantage of leaving the summer months free for collecting a stock of materials, in particular charcoal. But even in the sixteenth century, when there was no such shortage of fuel as to restrict production, the longest campaigns of the year were in winter. This was mainly because furnaces worked better and drove more rapidly in clear and cold weather. That the moisture contained in the air absorbed heat by its evaporation when it came in contact with the incandescent coals, seems to have been recognised quite early. The colder the air, the less moisture it contained. The early ironmasters, however, were not aware that the better working in frosty weather was actually due to the greater condensation of air by the cold and the consequently greater volume of blast driven into the furnace.

An output of one ton in twenty-four hours was the average output of the English blast furnace in the second half of the sixteenth century, which corresponded to output figures from the Continent. An increase commenced around 1610 and went on progressively until about 1650, at which date the high figure of from two to three tons was reached. The iron industry of the Weald, however, had no part in the progressive development, for in the whole course of the seventeenth century the highest level attained was little more than 1 ton 5 cwt.

Very few figures are available to show the yield of metallic iron from the ore. It depended on the richness and fusibility of the ores. In Richard Boyle's Irish furnace at Kilmackoe, for instance, the yield of iron from ore and old bloomery slag imported from the Forest of Dean was 40% in 1608, which is exactly the same percentage as at Parkend furnace in the Forest of Dean with a similar charge in 1654. In 1655, Boyle's son obtained a yield of not more than 25% from the poorer Irish ores smelted at Araglyn. The yield from Sussex ores varied from about 12% to 41%.

1 At Pannierbridge, in Sussex, e.g., the campaigns of 18 weeks and above were all conducted in winter, Pe., passim. See also App. X (Rieualux) and App. XVI (Pontypool and Llanelly).
2 Ruabon furnace, Denbighshire, e.g., remained idle in 1648 'by reason of the wett summer', NLW, Chirk Castle, F.13.148 — In Britain the quality of the iron produced in the months of June, July and August was reduced by 30% and the quantity to two-thirds or three-quarters, Th. Cooper, The Emporium of Arts and Sciences, New Series, vol. 1, pp. 135—136. Philadelphia, 1813.
3 App. IV — The blast furnace at Moyeuvre in Lorraine produced 1 ton in 24 hours in 1565, Ste., 1905, p. 942 — In the district of Siegen in Westphalia production was slightly higher with 1 ton 5 cwt. in 24 hours about 1550, and 1 ton 4 cwt. about 1600; J. Ph. Becher, Mineralogische Beschreibung der Oramen — Nassauischen Lands rührt einer Geschichte des Siegischen Hutten und Hammerstämme, pp. 191, 268. Marburg, 1789 — See also Johannson, p. 287.
4 Cork MS, vol. 7, No. 100; vol. 28, No. 44; Boote, pp. 156—157, estimated the yield from rich ores in Ireland at 40%, but 'ordinary' yield at 33% — PRO, SPD, Interregnum, vol. 81, fol. 7 (Parkend).
5 Approximately 12% at Newbridge in 1546—49, Straker, p. 250 (erroneously dated 1539). By Ray's statement of 1674 (App. XIV) it was 33%. At Frith furnace in West Sussex

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In Staffordshire and in the Sheffield district the yield from the local ores was approximately the same as in the Weald. It was, however, much higher when it was mixed with the red haematite ore from north Lancashire and Cumberland.¹ The red haematites of the north-west yielded the highest percentage of metallic iron, 46% and upwards. This accounts for their exportation over a wide area extending from north Ireland and the west of Scotland to Sussex.²

in 1648 it was 41% (Documents of Lord Leconfield, Petworth), but at Heathfield in east Sussex not more than 27%, Sussex AC, vol. lxvii, p. 30 (in 1738, from unburnt local ore).

¹ At Hales furnace, south of Dudley, around 1700, about 29%, at Mearheath 32%, Johnson, pp. 28, 58 — Sheffield district 16% from local ores, H. G. Baker, 'Some early Ironworks in Hallamshire', Lecture, Sheffield, 1944.

CHAPTER XV

THE CASTING BRANCH

The principal product of the charcoal blast furnace was pig iron for the forge. Castings generally constituted only a fairly small percentage of the total output. The $3\frac{1}{2}$% of castings in the production of Rievaulx furnace in the winter campaign of 1591–92 are quite characteristic in this respect. In the whole course of the sixteenth and seventeenth centuries castings here never rose above 5% of the furnace output. Only at the furnaces which produced guns and shot the output of castings was very much higher.

CANNON AND BULLETS

Of all the early furnace products of Britain none are better known and none were more valued than the cast-iron cannon.

'God hath so equally divided the advantage of weapons between us and Spain, that their steel makes the best swords, our iron the most useful ordnance.' These words were used by an English historian of the seventeenth century when he referred to the cast-iron guns formerly produced in Sussex. The high repute of the English cast-iron guns was still remembered in the eighteenth century, when David Hume, the famous historian and philosopher, described ship-building and the casting of iron guns as the sole arts in which the English had excelled. In respect of gun-casting, he asserted, the English manufacturers 'seem, indeed, to have possessed alone the secret'.

The secret which ensured the English manufacturer complete superiority combined with an unrivalled prosperity, was kept for no more than about a century. When the English method was discovered by foreign competitors, formidable competition arose on the Continent, increasingly detrimental to the industry in Britain.

In 1543 the casting of guns and shot commenced on a scale which

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far surpassed any earlier production in England, and this was mainly owing to the efforts of the English ironfounder Ralph Hogge and his master, William Levett, the parson of Buxted.¹

The largest order for iron guns was given to Levett in 1545, when a Scottish invasion was imminent and a French armada approached the coast of England. Levett was ordered to make 120 iron guns and a large amount of gun-shot. Their manufacture took nearly two years. Some of these guns went to the fortress of Portsmouth, others to the Isle of Wight. In the list of ordnance placed at the defences of Portsmouth, dated 16th February 1547, four 'sakers' of cast iron of Parson Levett's making are mentioned. 'Sakers' were guns of the smaller type of Tudor ordnance. In the list of 1547 the guns of Levett's making were the only cast-iron guns of English manufacture; the others were imported from Flanders.²

The manufacture of large cannon such as heavy siege guns required a larger quantity of cast iron than could be produced in the comparatively small furnaces of the time. This demand led to the building of a double furnace in the Forest of Worth, west of Ashdown Forest. Worth and Sheffield belonged to Thomas Seymour, Duke of Norfolk, until his attainder for high treason in 1546, when his property in Sussex became forfeited to the Crown. On 27th December, William Levett was commissioned to oversee the Duke's ironworks and mines. Under his supervision the double furnace was erected at Worth in 1547; it was the first of that kind in England. A double furnace consisted of a pair of furnaces standing side by side and combined in a single structure.³

In 1574, two other double furnaces were built in Sussex. These were at Newbridge in Ashdown Forest and in the parish of North Chapel, probably at Frith.

There is no picture of an early English double furnace. The earliest is a ground plan of a double furnace at Madeley Wood, in Shropshire, erected by Abraham Darby III in 1776. The plan is quite in keeping with an eighteenth-century ground plan of a double furnace at Finspong in Sweden. The main difference between the two is in the supply of water to the wheel that moved the bellows. At Finspong the wheel

¹See above p. 171.
³The idea of the double furnace for casting heavy cannon came from the metal industry. The first known was erected in 1452 by a Hungarian, named Orban, when the Turkish Sultan Mohammed II gave orders to produce large guns for the siege of Constantinople, Fouilkes, loc. cit., pp. 13–14. About half a century later, it was known in Flanders, C. St. Smith and T. Gnudi, The Pirutecnia of Vannoccio Biringuccio (first edited in 1540), p. 285. New York, 1942. From Flanders, it may have been introduced into England, since Henry VIII obtained large quantities of cannon from Flemish founders.

Swedenborg (1734), p. 158, spoke of the double furnaces in England as something already belonging to the past and made unnecessary, since the hearth for gunfoundering had been widened by that time.

S—H.I.S.
was moved directly by a current of water in the way generally used up to the late eighteenth century. At Madeley Wood an engine was used for pumping the water first in a pool from which it could flow to the wheel.¹

The first products of the double furnace in Worth Forest are known to us from an inventory of 22nd January 1549.² There were smaller guns, such as sakers, minions and falcons, and heavy guns also, e.g.

Fig. 28. A plan of the ironworks at Madeley Wood in Shropshire, by George Perry.

British Museum, Map Department, K.36.16.1.

fourteen culverins and sixteen demi-culverins. Apart from these guns left at the foundry others had been cast which were sent to Southwark. Probably they were the 'iron pieces' made by Levett for the King's use in 1547-49.

When William Levett died in March 1554, he was succeeded by his servant Ralph Hogge, who built 'Hogge House' at Buxted, where he lived until his death in 1585. During his long career as an iron-founder Ralph Hogge produced a great number of guns and munition, delivered

² Printed: Sussex AC, vol. xiii, p. 128; Straker, pp. 462-463.
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principally to the Office of the Ordnance in the Tower. In 1575–80 one of his factors was in charge of 230 tons of iron ordnance, 231 tons of wrought iron, 101 tons of sowes, 33 tons of iron shot, all manufactured at Hogge's ironworks.

In 1567 Queen Elizabeth granted Hogge the monopoly of exporting 'cast iron ordnance with gunstones' to foreign countries, provided that they were not required by the Office of the Ordnance. This privilege was infringed by others who set up gun foundries in Sussex. In 1573 there were six such foundries, apart from Hogge's at Oldlands; one of them, at Mayfield, was the property of the famous Thomas Gresham. From Hogge's complaint against this infringement of his rights we know into which countries ordnance was exported, namely Denmark, Flanders, France, Holland, Sweden, and Spain. The exported guns were of every type, from falconets to demi-culverins, but they were mostly of the smaller type. Apart from ordnance exported to the Continent, large quantities went to English ports, such as London, Bristol, Plymouth, Portsmouth, Southampton. It was mostly used for the defence of the country and for the armament of warships, and enabled the British Navy to gain the glorious victories of the Elizabethan era.

The principal foreign purchasers of English guns were the Dutch, during the war of liberation from the Spanish yoke in the later part of the sixteenth century. Such purchases continued in the seventeenth century, when the Dutch Navy continually increased in size and importance, so that Holland became the principal maritime power.

No effort was spared by the Dutch to procure cast-iron guns manufactured in England; for example, in the years 1615 to 1618 they were purchasing half the produce of John Browne's gunfoundry at Brenchley in Kent. He employed two hundred men (a very considerable number in this early period), to use his own words, 'the Dutch having bargained with him to take of all that the English doe not buy'; the number of guns ready for transportation from the works to Holland amounted to six hundred during those years.¹ Frequently Dutch merchants such as Ludolph Engelstedt and Giles de Vischer, in 1594 to 1596² acting as special agents for their Government, stayed in England to buy cast-iron cannon and to procure export licences from the English Government.

The majority of the guns cast after 1543 were larger and heavier than those cast earlier. The guns cast by Symart in 1509 had an average weight of 7 cwt., the chambers of 2 cwt. 17 lb. Reynold's cannon weighed 8 cwt. 35 lb. per piece.³ The guns cast of iron between 1547 and 1609 were mostly falcons, minions and sakers and their weights

¹ PRO, SPD, James I, vol. 105, No. 42.
³ App. VI, and above pp. 164 and 167.
were from 9 to 13½ cwt.¹ From the time at which double furnaces were built, the first in 1547 at Worth in Sussex, larger guns were cast.² But they were fairly rare in the latter part of the century. One of the largest cast towards the end of the century is reproduced on Plate XXI.

Unfortunately, the available evidence does not supply complete figures of weights, lengths and calibres or bores. The list published by Laird Clowe and reprinted by Straker is based on cannon made of brass, not iron, which are preserved at the Rotunda or Artillery Museum at Woolwich, and similarly with subsequent lists. Only one, also published by Straker and based upon casts at Sussex furnaces in the years 1735, 1742, and 1765, deals with iron guns, but is very incomplete.³ Evidence supplied by documentary sources and the few early guns of cast iron preserved at Woolwich, is compiled in the table shown on p. 251.

The number of furnaces casting guns and shot varied greatly. In 1573 the total was nine, all in Sussex (except for one in Kent) with an annual output of 500 or 600 tons.⁴ The number increased to eleven (ten owners) in 1576, but no output figures are available. They were all in the Weald. There was one more gunfoundry at Abercarn, Monmouthshire, so that the total number is twelve.⁵ Shortly before the Spanish attempt to invade England, which was foiled by the victory over the Armada in 1588, the output of guns had increased; it was estimated at 600 or 700 tons yearly in 1585.⁶ In 1592 the number of furnaces was nine with a total output estimated at 2000 tons, a figure which may have been too high, since for 1601 and for some years earlier, the estimate was 800 tons.⁷ All in all, the annual output of guns appears to have increased between 1570 and 1600 from about 500 or 600 to 1000 tons, but it is unlikely that it ever was more.

After peace was restored the number of gunfoundries seems to have fallen again, for in 1609 only five are on record, three in Sussex and one each in Kent and in Glamorgan (Pentyrch).⁸ Shortly afterwards gun

¹ Four sakers cast by Wm. Levett in 1547, PRO, SPD, Hen. VIII, Bundle 1, No. 20 — In 1573 two demi culverins only, but twenty-eight smaller guns, Straker, p. 151 — 1569-70, PRO, SPD, Eliz., vol. 67, No. 37 — At Abercarn, Monmouthshire, erected 1576 (App. V), guns from falconets to sakers, E. G. Jones, Eschequer Proceedings (Equity) c. 861 Conc. Wales, p. 251. Cardiff, 1599 — 1609, PRO, Eschequer Special Commissions, No. 4143 — In 1592 the export of guns was limited to 'small pieces, as falconets, minons and certain few sakers', Cal., SPD, Addenda, 1580-1625, p. 416.
² Inventory of 1549: fourteen culverins and sixteen demi culverins against twenty-three sakers, minons and falcons, Straker, p. 492.
⁴ Seven mentioned by Hogge in 1573 to which the double furnaces at Mitchell Park and Newbridge should be added. Straker, pp. 150-152, 250, 429.
⁵ BM, Lansdowne MS 683, fol. 21v.
⁷ Nesc. Tr., vol. xix, p. 43.
⁸ PRO, Eschequer Special Commissions, No. 4193.


<table>
<thead>
<tr>
<th>Name of gun</th>
<th>Weight</th>
<th>Length</th>
<th>Calibre</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demi cannon</td>
<td>59 cwts. 11 lb.</td>
<td>Ft. ins. 9 6</td>
<td>ins. 7</td>
<td>Woolwich, Rotunda Museum, Class III, No. 5. Cf. Ffoulkes, loc. cit., p. 46 (ad 1595). Illustration see Pl. XXI.</td>
</tr>
<tr>
<td>Culverin</td>
<td>About 40 cwts.</td>
<td>10 11</td>
<td>4.25</td>
<td>Woolwich, Class III, No. 6, from Pevensey Castle, reign of Eliz. I.</td>
</tr>
<tr>
<td>Demi Culverin</td>
<td>25 cwts.</td>
<td>9 0†</td>
<td>(4)*</td>
<td>1588, Cal., SPD, Addenda, 1580–1625, p. 254.</td>
</tr>
<tr>
<td>Saker</td>
<td>1514 lb. = 13½ cwt.</td>
<td>8 6†</td>
<td>(3.65)</td>
<td>1569–70, PRO, SPD, Eliz., vol. 67, No. 37.</td>
</tr>
<tr>
<td>Minion</td>
<td>(1050 lb.)</td>
<td>6, 6½, 7 ft. mostly 6 and 6½.</td>
<td>(3.5)</td>
<td>1704, cast at Robertsbridge, Sussex, Penshurst Place.</td>
</tr>
<tr>
<td>Falcon</td>
<td>9 cwts. (680 lb.)</td>
<td>4 and 4½ ft.[2] 7 ft 3 ins. and 7 ft. 4 ins.[3]</td>
<td>3[8]</td>
<td>1567 BM, Egerton MS 2723 (weight).</td>
</tr>
<tr>
<td>Falconet</td>
<td>(500 lb.)</td>
<td>3 and 3½ ft.[3]</td>
<td>(2)</td>
<td></td>
</tr>
</tbody>
</table>

* Figures in brackets apply to brass guns.
† Figures taken from iron guns cast at Horsmonden in 1679. Archives of the Hutton family, CRO, Lewes.
\[2\] Figures taken from iron guns cast at Robertsbridge in 1704, Penshurst Place.
\[3\] Woolwich, Rotunda Museum, Class III, Nos. 11 and 12 (sixteenth and seventeenth century).

Founding extended into Ireland. The first who took it up was Richard Boyle, in about 1619. A licence to produce and export ordnance and shot into the Low Countries apparently was not granted, but this was no deterrent. According to information the Privy Council had obtained by 1623, Boyle had set up a gunfoundry. Others intended to do the
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The same. These were two former clerks of Boyle’s ironworks, who after various attempts succeeded in 1628 in obtaining a licence to cast guns and shot and also to make bar iron for the King’s service in Ireland. By 1632 or 1633, however, their activities had slowed down considerably, if they had not ceased altogether. The civil war which started in 1642 gave a new impetus to gunfounding in the Weald. Twenty-six furnaces, referred to in 1653, were engaged in the production of guns and shot for Charles I, and so were two furnaces (Cannop and Lydbrook) in the Forest of Dean. In 1664, eleven furnaces operating in the Weald made cannon and bullets for the Dutch war, and thirteen further furnaces were restored and stocked. The most important gunfounders in the Weald during the seventeenth century were the Brownes of Brenchley and Horsmonden in Kent, and in the eighteenth the Fullers of Heathfield, in Sussex, but by this time the Sussex foundries were closing down one by one.

The above-mentioned blast furnaces produced other things besides guns and shot. There were no furnaces which produced castings exclusively, although Ralph Hogge in 1573 referred to seven in Sussex which ‘dayly’ cast guns and shot. Hogge himself produced pig iron as well as guns and bullets at his furnaces. The same applies to other furnaces. At Worth, in Sussex, e.g., ordnance and shot as well as ‘raw yron’ for conversion in the forge were produced in almost equal quantities from 1546 to 1549. Dyffryn furnace in Glamorgan produced both kinds of iron from 1575 to 1584. This practice was partly for technical reasons. Production of castings of all sorts did not commence before the ‘campaign’ had proceeded for some weeks and the furnace was well heated. Even then it was carried on only at intervals.

Continuous production was impossible without exposing the furnace to the danger of cooling off too much. This danger was greatest with the casting of shot, since the metal was taken out of the furnace by ladles and poured into moulds, which rendered it necessary to turn off the blast for a considerable time. Major John Wade who in 1653 was com-

1 Grosart, first series, No. 1, p. 237 — APC, 1623–25, p. 27 — Shot moulds are mentioned in the inventory of Kilmackoe in 1619, Cork MS, vol. 10, No. 39. See also, ibid., vol. 16, Nos. 49 and 71 (attempts to get a licence).
4 Straker, pp. 164–165.
5 Floulkes, loc. cit., pp. 76–79. A gunfoundry at Vauxhall in London erected about 1647 was operated for about twenty years only, ibid., pp. 50 et seq. A limited recovery took place in Sussex around 1700, owing to demands for military supplies, VCH, Sussex, vol. iii, p. 248.
6 Hogge’s statement, Straker, p. 150, see also above p. 172.
7 Arch. J., vol. 69, p. 281 (Worth) — Chancery Proceedings, loc. cit., Eliz. A2, No. 50 (Dyffryn) — The practice continued, e.g., at Robertsbridge in 1703, Penshurst Place. At Waldron, Sussex, 1690–91: 109 tons of castings (mostly shot) and 90 tons of pig iron, BM, Add. MS 33156.
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missioned by the Admiralty to erect a furnace in the Forest of Dean for the casting of bullets, pointed out this danger and successfully urged the Admiralty to permit the use of the furnace for production of pig iron as well.¹

The figures of furnaces and their output naturally fluctuate; with an upwards trend in wartime and a fall when peace returned. Even in peace-time production would have been much higher had it not been for legislation which limited the export trade of ordnance for fear that war material produced in England would find its way to the country’s enemies. As early as 1573² Ralph Hogge pointed out that in addition to the existing furnaces new ones were going to be erected by gunfounders in the Weald and also in Wales. The incentive was the high prices paid for guns. Their manufacture was the most profitable proposition in the sixteenth-century iron trade.³

The high price of English guns was no deterrent to continental purchasers, since they were well aware of their superior quality. This is reflected in their frequent attempts to induce English founders to work abroad, and to obtain cannon by illegal trade and bribery, if they could not be procured from English founders authorised to sell abroad.⁴ Moreover in 1598, an Englishman wrote from Spain that all seafaring men agree ‘that they never see cast ordnance of iron but such as is made in England’.⁵ More convincing than the demand from the continental market is the term ‘after the English fashion’ applied to the casting of iron guns in German Westfalia in 1592, and in Sweden in 1600.⁶ This term clearly signifies that English gunfounding was the model for their colleagues on the Continent.

Naturally foreign gunfounders could not rest until they had found out what the ‘English fashion’ of casting was. The first, who in 1620 claimed to have succeeded by discovering the secret on journeys they made in England and from iron-merchants they met on the Continent, were two citizens of Namur, in Belgium, Henri de Harzemp and

¹ PRO, SPD, Interregnum, vol. xI, fol. 129: ‘In the castings of shot there is much delay in the works, for the furnace must stand still for a season whilst the mettll is taken out with ladles and put into moulds and therefore, if it should continue still castinngs of shot, it would cooe and at last blowe out’.

² Seven mentioned by Hogge in 1573 to which the double furnaces at Mitchell Park and Newbridge should be added. Straker, pp. 150–152, 250, 429.

³ From the very beginning guns were priced higher than anything else produced at ironworks. In 1548–48, e.g., ordnance from Worth, in Sussex, sold at £10 per ton but bar iron mostly at £8 or £9, Arch. Jo., vol. 69, pp. 308–309. In 1598, the profit yielded by ordnance was estimated at £10 per ton, Cal., SPD, Addenda, 1580–1625, p. 416.


⁵ Newe. Tr., vol. xix, p. 45.

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Guillaume de Moniot. They erected furnaces in the vicinity of Namur to put their discovery into practice. This was the starting point of a competition which intensified when shortly afterwards gunfounding was introduced from Liège into Sweden. The superior Swedish ore made it possible to produce guns which finally ousted the English cast-iron cannon from the Continental market.

In general, the method employed in England was the same as on the Continent. The guns were cast around a core or 'kernel bar', to the lower end of which a 'crown-iron' was attached to prevent the core from moving in the mould. When everything had been prepared, the mould was lowered, with the breech downward, into a pit in front of

the furnace, and the liquid iron was run in. Since in casting on a core certain roughnesses in the bore were bound to occur, the bore (or calibre) was seldom exact. To clean the inside of the gun, boring appliances had to be used such as the radial drill. The method employed in Sussex was horizontal boring, i.e. the gun was laid on a bed and the drill, revolved by water power, was gradually advanced.

The transition from core-casting to casting in one solid piece, which afterwards was bored, does not seem to have taken place before 1700.2

The above-described process does not show in what respect English

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1 J. Borgnet, Analyses des Charbons Namuroises, Extrait de tome V, No. 2, une série des Bulletins de la Commission Royale d'Histoire, pp. 119, 134. Bruxelles, 1863 — In France, the secret seemed to be known not much later, since in 1627 a Frenchman, who acting on behalf of the Duc de Bouillon tried to persuade Sussex founders to go to France, disclosed that an English founder had already settled there, PRO, SPD, Charles I, vol. 65, No. 95.

gunfounding excelled. On the Continent boring was also employed in
the manufacture of cast-iron guns, e.g. at Liège in 1575. The cast iron
preferentially produced in Sussex in the sixteenth century was grey
cast iron which is clearly shown by the microspecimens of cast-iron
firebacks of the same period. This, however, was nothing extraordinary
either, since it was produced in Belgium also.¹ To explain the superi-
ority of English guns Rhys Jenkins has pointed at two facts. Firstly,
Sussex founders had extraordinary skill in loam moulding, and
secondly, the proportions of the guns were entirely different from those
cast before 1543 and apparently also from those cast on the Continent
in the same period.²

The correctness of the second statement is borne out by all the
available documentary evidence. The earlier guns, such as those
produced at Newbridge in 1509, were of the mortar type, of short
length and of large calibre (from 11 to 18 inches). They were equipped
with detachable chambers. Chambers are never mentioned with any of
the iron guns cast at Buxted or anywhere else in the Weald since 1543.
From that time onwards the guns were cast in one piece. They also had
proportions quite different from those of the earlier guns or mortars.
The reference to the several calibres (de plusieurs calibres) by the above-
mentioned two Belgians, probably refers to this. The guns were longer
and of smaller calibres, which ensured a much greater propelling power.
This was a tremendous advance.

The method of making the mould was also very important. The use
of loam instead of sand made it possible to apply a much greater heat
for drying. A well dried mould prevented steam evaporating from the
loam when it came in contact with the liquid iron, and eliminated the
danger of cavities being produced in the iron by vapours.

The risk of blow holes being produced was greatest at the top where
the iron came in contact with the air from outside. This was prevented
by the formation of a 'gun head' which was a mass of metal projecting
beyond the muzzle of the gun and of somewhat larger diameter. Apart
from firmly closing the top so that no air could penetrate into the metal
of the gun from without, the object of the gun head was to provide for
contraction of the metal in cooling, and also to receive the slag and
other impurities which, on account of their lower specific weight, had a
tendency to rise to the surface. In England the gun head was of con-
siderable height.³ This also may have contributed to the production of
an improved cast which excelled in purity of metal, and in density
and tenacity.

¹ Évrard, pp. 42, 207, 277 — App. VIII.
³ Lewis, vol. iv, p. 167 — John Fuller of Heathfield furnace in Sussex wrote in a letter
of 1743 to the Ordnance Office in London that the gun head which 'draws in holes from the
outward aire' was made so large that it 'usually' weighs an eleventh part of the whole gun,
Battle, Fuller MS.
The method employed to improve the metal for the casting of bullets was in principle the same as that for gun founding. The scum floating on the surface of the metal in the hearth was let out repeatedly before the residue of liquid iron was considered good enough for casting. In the early eighteenth century a particular device was employed which ensured that only the purest iron was used for the casting of shot. This was an iron plate called a ‘false timp’, which was let down into the forehearth in front of the timp stone.

![Diagram of timp and dam stones](image)

**Fig. 30. False timp.**
*From Lewis, vol. iv, p. 165.*

The metal rising in the space (a) between the timp and the damstone was skimmed first and then ladled out. It was replenished with the purer part of the liquid iron which from the bottom of the hearth (b) passed underneath the false timp into the space (a).  

### CAST IRON FOR DECORATIVE USE

**Firebacks**

Compared with the production of ordnance and shot the production of such domestic and decorative objects as firebacks was to begin with very small. In the years 1547 and 1548, in which firebacks are referred to for the first time in English history, 56 tons 1½ cwt. of ordnance and 52 tons 5 cwt. of bullets were cast at the furnace of Worth in Sussex, but of ‘small cast ware’ only four ‘plates for chimneys’. It was not until the latter part of the century that the number produced commenced to increase.

Firebacks were designed to go against the back wall of the large open fireplaces which can still be seen in some old houses. The iron plates protected the stone or brickwork from the crumbling effect of fires. The older firebacks were larger and heavier than later ones, on the

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1. Parkend furnace, Forest of Dean, in 1653: ‘many times the top or scum of the metal must be let run into pigs beinge not fit for shot’, PRO, SPD, Interregnum, vol. xi, fol. 129v.
average weighing between one and three cwts.¹ The reason why at the initial stage production of firebacks was extremely small and even later increased but slowly, was the slow pace at which the recessed fireplace with chimney was introduced. The recessed fireplace replaced the open fires of the Middle Ages which were placed in the centre of the hall; as there was no chimney the smoke was allowed to escape through an aperture left in the roof. The recessed fireplace with chimney was introduced into the hall of the English manor house in the fifteenth century, but not earlier than in the course of the sixteenth century did it find its way into the general living room of the yeoman. Even then, although chimneys became quite common in towns, it took a long time until the fashion really penetrated into the country.²

It is impossible to say precisely when the casting of firebacks began in England. Of all the English firebacks bearing a date, the most ancient is of 1548, which date coincides roughly with the first documentary evidence mentioned above.³ It has often been asserted that the casting of firebacks started in this country before the end of the fifteenth century; but this seems very improbable. The idea is based mainly on the 'Gothic' character of some of the early English firebacks. Yet Gothic designs were still quite commonly applied to firebacks cast on the Continent during the first half of the sixteenth century, and considering the very limited expansion of the blast furnace before 1540, and also the fact that the production of arms was the principal concern in the early days, it does not appear likely that casting of firebacks commenced in England much earlier than about 1530 or even 1540.⁴

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⁴ Professor W. R. Lethaby, ('English Cast Iron', The Builder, London, 1st October 1926) doubted whether any of the firebacks preserved in the Victoria and Albert Museum attributed to the fifteenth century 'are actually earlier than the middle of the sixteenth century.'
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The method was quite simple. A bed of sand, well compressed, was prepared on a layer of cinders (slags). Artistic designs, carved in wood, were pressed into the sand, and the liquid iron was then poured in to solidify in the shape required.

Fig. 31 shows a mould with pattern stamps in place.

Small movable stamps (dies) of wood were used, into which the selected designs had been cut. Sometimes separate objects such as the founder’s hand or pieces of stiffened rope were pressed directly into the sand instead of stamps. This primitive method prevailed in England in the sixteenth century. By about 1600, however, it had been almost completely abandoned.

Shortly before 1550 a new and more advanced method was introduced. Instead of movable stamps or single objects, a model all in one piece, into which the whole design had been cut, was pressed into the sand. The first dated specimen of this new type in England, was the above-mentioned fireback of 1548. Apart from a few isolated cases, the new method was applied to all the firebacks produced in Britain in the seventeenth and eighteenth centuries.

In the extensive literature dealing with the subject firebacks are often classified according to the character of the designs they bear, but it is very hard to date any fireback by its design.

The Firebacks of the Sixteenth Century decorated by using separate movable stamps.

The view has been expressed frequently that the earliest firebacks cast in England were those exhibiting Gothic tracery and vines with grapes and leaves. The best known of these is an elaborate fireback preserved at the Victoria and Albert Museum in London. It is usually ascribed to the late fifteenth century. The vines were carved into long narrow boards arranged in vertical lines; on the top is a group of birds regardant. On other backs the vine boards were arranged in various ways, so as to produce a variety of patterns, or spaces were left between them, to be filled in with different motifs such as birds and pomegranates.  


2 Illustrations: Sussex AC, vol. 46, Plate 8a — A. Kippenberger, Die Kunst der Ofenplatten, Abbildung 1, p. 10. Düsseldorf, 1928 — Straker, p. 169 — Glaug and Bridgewater, loc. cit., Fig. 18, p. 21.

3 See App. VIII, No. 1: Boards arranged to form the letter ‘A’. — See also Lewes, John
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The bird regardant, already represented on the fireback in the Victoria and Albert Museum which is believed to be one of the first cast in England, is supposed to have been the badge of the Fowles, a prominent family of Sussex ironmasters. Originally yeoman farmers, they seized the opportunity of the rapidly expanding iron industry in the Weald, and became ironmasters operating furnaces and forges in the vicinity of Rotherfield from about 1560 onwards. These dates do not square with the assumption that firebacks exhibiting birds regardant were produced in the early part of the sixteenth century or even in the fifteenth.

Compared with other artistic designs used in England in the sixteenth century, the motif of the vine, combined in some cases with the bird regardant, is rare and occurs in Sussex only. On the Continent the vine motif was confined to a limited region also; the wine-growing country approximately between Liège in the north and the Moselle in the south. It may have been introduced from the original production centre on the Continent into Sussex. This probably symbolised a family tie. In Sussex the bird regardant, which does not appear on Continental firebacks, was added. The evidence, though scanty, suggests that the first firebacks of the type described were brought over from the Continent and served as patterns for firebacks afterwards cast in Sussex and produced perhaps between 1530 and 1560. In the Continental region which may have been the source, the Gothic character prevailed until about 1550.

A very simple form of ornamentation which was much more used than vines, birds and Gothic tracery, was achieved by pieces of rope stiffened with pitch or glue and pressed into the sand bed. They were arranged so as to form borders and simple designs such as crosses, sacred

Every Bequest, No. 28, Architectural Review, vol. 38, Fig. 2, p. 59; Connoisseur, vol. 46, Fig. vi, p. 202.


2 See Kippenberger, loc. cit. Tafel 7 and 8 (at the College of Eupen, south east of Liège) — A fireback with vines and bearing the date of 1540, is preserved in the Musée de Stavelot, south of Liège — A much appreciated wine was cultivated in Belgium in the Middle Ages and later; evidence kindly supplied by Mr. Paul André, Conservateur du Musée de la Vie Wallonne, Liège. The English traveller Dr. Edward Brown who visited Liège in 1673 remarked on the wine cultivated in the district, although he did not think much of it, E. Brown, A Brief Account of Some Travels, second edition, p. 189. London, 1685.

3 Cardinal Reginald Pole stayed twice in Belgium, first in 1537 in which year the Bishop of Liège lodged him in his own palace, and again during the years of 1553 and 1555, at Brussels, Dictionary of National Biography, vol. 46, pp. 38, 41-42. London, 1896 — A fireback with Gothic tracery and grapes (see illustration in Connoisseur, vol. 46, p. 201, Fig. 3) now preserved at Lewes, has a striking resemblance to cast-iron plates produced at a furnace near Stolberg which belonged to the Dukes of Cleves (evidence kindly supplied by Dr. F. Hellwig, Düsseldorf). It may have been brought to England after the marriage of Henry VIII to Anne, the second daughter of the Duke of Cleves, in 1540; she later lived at Anne of Cleves’ house at Lewes.

monograms and lettering. These, in particular the crosses, were credited with the power to expel evil spirits.\(^1\) Ornamentation by rope-lines was used to such an extent in sixteenth century England, that the number of firebacks thus decorated exceeded that of all the others cast in the same period. The fashion had a parallel in the north-east of France and extended into Belgium. It was much in vogue in the Champagne, Bar-le-Duc, and Lorraine.\(^2\) The English rope-line designs closely resemble those of the Continent, so it seems likely that they may have been introduced here from abroad. Of the two firebacks reproduced in App. VIII, Nos. 2 and 3, one comes from Sussex and the other from Virton (Belgium). In the centre of both is a Pentagram to protect the domestic hearth from evil spirits, which was a magical symbol credited with the power of protecting against evil spirits and witches. It still was used in ornamentation of firebacks in the late sixteenth century.\(^3\)

A tendency towards British independence of foreign designs is apparent on two firebacks on which objects in addition to rope-lines are used for ornamentation. One is a firedog,\(^4\) the other is the hand of the founder with a pair of compasses.\(^6\) One pattern for firebacks which was apparently quite popular as it was produced in several specimens slightly varying in the arrangement of the artistic motifs, has a medley of designs, mostly of heraldic character.\(^6\) On one of these, reproduced in App. VIII, No. 6, a crowned quartered shield representing the Tudor Arms, with two supporting lions and a crowned and barbed quatrefoil rose, is repeated twice. The space left is filled with monkey-like figures and two rope-line designs which may be sacred monograms. A tendency towards a more homogeneous composition is apparent on a later fireback from Kirby Frith Hall, in Leicestershire, cast in the reign

\(^1\) See App. VIII, Nos. 2-4 — Lewes, John Every Bequest, Nos. 2-4, 13; Hastings Museum, L.A. 765; Architectural Review, vol. 58, p. 59, Fig. 2 (crosses) — Arch., vol. 56, p. 141, Fig. 3 (monograms) — Hastings Museum, L.A. 216 (rope-line lettering: letters TA and MT with a monogram between them).

\(^2\) Museums at Bar-le-Duc (in the Palais de Justice), Chalona-sur-Marne, Metz, Nancy (Musée Lorrain), Rheims (containing the largest collection in the world with more than 3,000 firebacks), Troyes, Virton (Belgium).

\(^3\) E.g. a fireback of 1574, Musée Lorrain at Nancy, another (not dated) in the museum at Metz, two firebacks (Luxembourg, Musée Nationale, and Düsseldorf, Collection of the Verein Deutscher Eisenhüttenleute, No. 65), both representing the arms of Philipp II of Spain as Duke of Burgundy (Cross of Burgundy, also in rope-lines) have two Pentagrams each. Actually the design is a derivative of the Pentagram since it has eight points instead of five, which is the main characteristic, the perpetual (unbroken) line, is preserved.

\(^4\) App. VIII, No. 4 — A fireback with two firedogs, preserved at Lewes, is reproduced in Arch., vol. 56, p. 145, Fig. 7 and one with three, at Hastings Museum, in Connoisseur, vol. 46, p. 198, No. 11.

\(^5\) App. VIII, No. 5. Reproduced in Arch., vol. 56, p. 140, Fig. 2, and Sussex AC, vol. 46, Plate 8a.

\(^6\) Illustrations: Sussex AC, vol. ii, p. 188, and vol. 46, Plate 80; Arch., vol. 56, p. 142, Fig. 4; VCH, Sussex, vol. ii, facing p. 242; Straker, p. 168; Gloag and Bridgewater, loc. cit., p. 19, Fig. 16 — Specimens are preserved in the Victoria and Albert Museum, London, at Lewes, Hastings (two) and various other places (see Arch., vol. 56, pp. 142-143).
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of Queen Elizabeth I. It still has rope-line borders and the designs are all produced by means of movable stamps, the traces of which are distinctly visible. The Tudor Arms are in the centre, and the shield bearing the arms is surrounded by the Garter and supported by a lion and a griffin. A crown is in the centre of the top between the letters ER. Spaces are decorated by four fleurs-de-lis placed irregularly. The fleur-de-lis, an emblem of the royal arms of France and of England as well, was often used without any other design.1 Somewhat similar to the fireback from Kirby Frith Hall, but less elaborate, is a group of three firebacks of 1589, apparently cast in the northern part of the Weald of Kent.2

Firebacks moulded from one-piece models

The tendency towards concentration upon a main central object, noticeable in the fireback from Kirby Frith Hall, is more significant on heraldic firebacks cast from one-piece models, such as the fireback reproduced in App. VIII, Fig. 8. It represents the arms of King Edward VI (1547–1553) in a quartered shield (three fleurs-de-lis, three leopards) surmounted by a crown and with a griffin and a greyhound as supporters. The date at the base (1548) makes it the earliest dated fireback in England. The fireback seems to have been much favoured in the sixteenth century, in England and on the Continent as well, since several specimens are preserved in Belgian and German museums.3 A fireback with the date 1579 and the letters ER, but without supporters, was discovered in Wales in the 1820s.4 Another heraldic fireback, simpler in decoration, has the Tudor rose in the centre of the shield and bears the date 1571.5

Simplicity in decoration, however, is not characteristic of all the sixteenth-century firebacks bearing the royal arms and cast from one-piece models. A fireback with the initials of Queen Elizabeth I and the date of 156. . . . e.g., is ornamented with elaborate scroll work.6 The same

1 Hastings Museum, L.A. 229; at Hampton Court (Arch., vol. 56, p. 151) and at Rheims, in France (almost the same plate); at Horsham Museum, and at Lewes (in three rows: 3:1:3), Commissaire, vol. 46, p. 198, Fig. III.
2 H. R. Schubert, 'A Rare Group of Wealden Firebacks', Jo., vol. 165, p. 39–40. One of the firebacks which had been for centuries at the Old Anchor Inn at Hartfield, Sussex, is now in the collection of the Carnegie Institute at Pittsburg, Pennsylvania, U.S.A. Reproduction in Arch., vol. 56, p. 149, Fig. 16.
3 At Ockwells in Berkshire, and a fragment at Anne of Cleves' house at Lewes, in Sussex. Musée Archéologique at Namur, Musée Curtius at Liège, in the collection of the Verein Deutscher Eisenhüttenleute at Düsseldorf (acquired from Grand Hallieux, near Stavelot, Belgium). Another found at Libramont in Belgium and now at the Musée Archéologique at Arlon, in Belgium, only has one slight difference from those noted. The outlines lead from the sides directly into the top arch without any break. Both types are reproduced by Évrard, p. 319, Figs. 144 and 145. See also Jo., vol. 176, p. 63.
6 Lewes, John Every Bequest, No. 25.

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applies to firebacks with arms of noble families, such as the very elaborate fireback of Hurstmonceaux, in Sussex, which has twenty-two quarterings and is ascribed to the sixteenth century.¹

The fireback commemorating the victory of the English fleet over the Spanish Armada in 1588, bears a combination of rope-lines, fleurs-de-lis, Tudor roses and anchors, which shows that the multiple and varied design had not yet been superseded by the central object.²

This concentration upon a central object was not common before the second quarter of the seventeenth century. Even then it was not characteristic of the majority of English firebacks, though it may be regarded as a distinctively English fashion. The effect is monumental almost, in many cases. The detail is less delicate than in the contemporary continental examples, but this is really more suitable to the heavy material—iron—and produces an impression of boldness and strength. A typical example of this style is reproduced in App. VIII, No. 11. It represents the phoenix, a favourite motif in the Christian world as a symbol of immortality. Compared with French firebacks the difference in style is obvious. In France this motif was handled with the greatest vivacity and an exuberance of ornamentation. By the spiral lines of the surrounding scroll-work the central figure of the bird was reduced in importance.³ On the Sussex fireback the phoenix in the flames with his wings spread is the only ornament within the simple framework.

Another fireback in the same style is reproduced in App. VIII, No. 12. The central figure represents St. Paul on the Isle of Melita, with outstretched arm, casting a serpent into the flames.⁴ There are many more of this type; e.g., the well-known fireback depicting the martyrdom of a Sussex man and woman,⁵ the Scotch lion dated 1649,⁶ Charles II on a prancing horse,⁷ the lion and the lamb dated 1679.⁸ Related to this group is the Lenard fireback of 1636 with the large figure of the

¹ Specimens at the museums of Hastings, Maidstone, Rochester, and Victoria and Albert Museum in London — Reproductions: Sussex AC, vol. 46, Plate 8m; Arch., vol. 55, p. 155; Fig. 19; Connoisseur, vol. 46, p. 202, Fig. viii; Straker, p. 171.
² App. VIII, No. 10 (fragment). The complete fireback is reproduced in Architectural Review, vol. 58, p. 61, Fig. 4, by Shuffrey, loc. cit., p. 198, and by Lethaby, loc. cit., p. 741, Fig. 1 (from 'a house near Victoria', in London).
⁵ Connoisseur, vol. 46, p. 204, Fig. x — Straker, p. 170.
⁶ Lindsay, loc. cit., p. 24, Fig. 12 — Gloag and Bridgewater, loc. cit., p. 27, Fig. 38.
⁷ Gardner, loc. cit., m, p. 166.
⁸ Lewes, John Every Bequest, No. 72.
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ironmaster in the centre. The fireback known as 'The Royal Oak' was very much in favour in the seventeenth century. It represents the oak of Boscobel in which Prince Charles, later King Charles II, concealed himself on his flight after the battle of Worcester in 1651. The fireback marks the transition to a more elaborate type which became fashionable in the second half of the century.

By that time the casting of firebacks had extended far beyond the Wealden area, following the march of the blast furnace. In Yorkshire firebacks were produced as early as 1583, in Ireland in 1612. After the restoration of the monarchy in 1660, cast-iron firebacks seem to have become more fashionable than ever, and were produced in large quantities. One ironmaster, George Sitwell, alone had about nine hundred cast at his furnaces in north Derbyshire in the two years 1664 and 1666. They had been ordered by ironmongers in London who sent moulds representing three favourite designs, the Phoenix, the King's Arms, and the Flower Pot.

The increased demand in the second half of the seventeenth century was an incentive to importation from abroad, which finally resulted in a change of style. Large consignments of firebacks came from Holland, after William of Orange had ascended the English throne in 1689. E.g. in the one year of 1695, a total of 1516 firebacks was imported from Holland. Many imported backs served as patterns for English ones.

The evolution of the ornamented fireback culminated in Holland in the seventeenth century. The Dutch backs were more richly decorated and narrower and higher than the majority of the earlier ones produced in England. They are particularly remarkable because of their elaborate frameworks composed of festoons of flowers and fruit, and other details. The domed top was often formed by two dolphins whose tails meet in a shell, dolphins and shell being the emblems of a sea-faring nation. The principal subjects selected were biblical, allegorical, or from classical mythology. The fireback reproduced in App. VIII, No. 14, is an early

1 See Plate xvii.
2 App. VIII, No. 13 — Reproduced Connoisseur, vol. 46, p. 206, Fig. xv; Gardner, loc. cit., vol. iii, p. 166.
3 At Rievaulx in 1583 'plates for the back of a chimney', Be., No. 1300 — In Ireland 'chimney backs' were cast at the furnace of Kilmackoe and sent to an ironmonger in London in 1612, Corks MS, vol. 4, No. 34 — C. G. Aman in Country Life, 25th January 1946, p. 173, presumed that a fireback with the Scotch arms, a fragment of which is in the Victoria and Albert Museum in London, may have been cast in Ross-shire 'a few years before 1603', but his arguments are not convincing.
6 Favourite subjects, e.g., were Neptune riding sea-horses, or the legend of the Rape of Europe, exhibited on two firebacks at the Museum of Brighton, both dated 1697.
T—H.I.S.
example of a biblical subject in the Dutch style. It appears to have been much in favour on the Continent and in England as well. The specimens still preserved are all slightly varying in the details of the framework. The scene represented is taken from the end of Chapter 24 of the second book of Samuel. The repentant King David is seen kneeling in front of an altar, on which a bullock is sacrificed as a peace offering to God to stay the plague from Israel. An angel with a sword and a scourge is seen above the altar.

Despite the turn towards a richly decorative style which remained predominant in the so-called Georgian firebacks of the eighteenth century, the older, typically English style of the seventeenth century was not completely superseded. The greater simplicity and the compactness achieved by concentration upon the centre, leaving surroundings and frame unobtrusive, is still shown on a fireback of 1717 reproduced in App. VIII, No. 15. This is a late example of a style which had emerged in England from a multitude of foreign designs, and at a late date was still sufficiently well-established to hold its place to some extent against a wave of new foreign designs imported from the Continent.

**Firedogs**

At about the time when the production of firebacks commenced in England, cast iron began to be used for the manufacture of firedogs. Firedogs, or andirons as they were sometimes called, were placed one on each side of the fireplace. The bars of the firedog, on which the burning logs rested, were made of wrought iron. The upright with its two feet was cast upon the bar. Uprights and feet were richly ornamented, closely following in this respect the artistic evolution of the fireback.

The first dated firedog is of 1575; another, rather similar in style, bears the inscription 'Hew Colin' which probably refers to Hugh Collins of Heathfield, in Sussex, whose will was proved in 1583. Judging by the

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1 A specimen differing by the addition of the initials H.S. is in possession of Mrs. Kenyon Mitford at Pittshill, Tilling, Sussex. Another, with a different framework (two angels) is in the Museum Gruthuuste at Bruges in Belgium. The replica of a third, the original of which is at Clevius and has no date, is in the collection of the Verein Deutscher Eisenhüttenleute (No. 61) at Düsseldorf.

2 The first documentary evidence is from 1545 in which year 'a pair of cast iron in ane diern' was sold for £3. Pe., No. 377(3). It was cast at Robertsbridge furnace, in Sussex. In 1548, a ton of 'andierne' was cast for Christopher Draper, an ironmonger in London and later Alderman of the city, who bought a fair amount of iron from Robertsbridge, Pe., Nos. 378(20) and 380(2). At Panningsbridge furnace andirons were cast in 1555, Pe., No. 378(4).


3 Lindsay, loc. cit., p. 16, Fig. 42 — Sussex Notes and Queries, vol. IX, p. 184 (with illustration), Lewes, 1944, vol. X, p. 8, Lewes, 1946-47.
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style, it would appear that the firedog (Pl. XXII) is older. The initials R.H. are believed to be those of the celebrated Elizabethan gunfounder Ralph Hogge who married at Maresfield, in Sussex, in 1560—after which date he and his wife were present several times at baptisms at the same church.¹

Graveslabs

Memorial slabs let into the floors of churches were generally less ornamented than firebacks or firedogs. A major part of the surface was required for memorial inscriptions to which was sometimes added a simple representation of the coat-of-arms. There are, however, a few more elaborately decorated graveslabs such as the memorial to Anne Foster in the church of Crowhurst, in Surrey, dated 1591.² In addition to the inscription, it shows two boys on one side and two girls on the other, all kneeling and praying, and also two coats of arms. The borders of the slab have been formed by using pieces of rope and a series of grape patterns. This elaborate ornamentation seems to have been admired by contemporaries, who used the graveslab as a pattern for firebacks.³ Generally, ornamentation was much simpler, as is to be seen from the numerous graveslabs still existing in many ancient churches in the country.⁴

One graveslab has aroused particular interest, since it was believed to be the oldest ever cast. This is the memorial of a ‘Jhone Collin’ in the church of Burwash in Sussex. By the ‘Lombardic’ character of the lettering and of the cross above the inscription, it has often been attributed to the fourteenth century. At present, however, it is most generally agreed that it was produced not earlier than about the middle of the sixteenth, perhaps in the reign of Mary (1553–58).⁵

¹ Maresfield Church Registers — Straker, pp. 398-399.
² Reproduced Straker, p. 175; Gloag and Bridgewater, loc. cit., p. 10, Fig. 9.
³ Specimens: Lewes Museum (Sussex AC, vol. 46, p. 49, No. 1064) and John Every Beguest, No. 29; another is at ‘Ye Olde Six Bells’ Inn at Billingshurst in Sussex, Sussex Notes and Queries, vol. xiii, p. 66. Lewes, 1950.
⁴ In Sussex from 1570 onwards, evidence from Straker, p. 176. The largest number at one place is in the church of Wadhurst (thirty-one with dates ranging from 1617 to 1771); some are reproduced by Gloag and Bridgewater, loc. cit., pp. 12-14, Figs. 10-12 — Eight graveslabs are at Burrington, in Herefordshire, reproduced: Royal Commission on Historical Monuments. An Inventory of the Monuments in Herefordshire, vol. iii, Plate 92. London, 1934.
⁵ Sussex AC, vol. ii, p. 178 — Illustrations: Arch., vol. 56, p. 135, Fig. 1; Straker, p. 307; Gloag and Bridgewater, loc. cit., p. 16, No. 8 — The earlier date has been rejected by Beck, vol. ii, p. 217, Lethaby, loc. cit., p. 528 (name does not suggest an earlier date than the sixteenth century, nor do the forms of some letters), and Rhys Jenkins, Nax. Tr., vol. xix, p. 39, London, 1940 (perhaps time of Queen Mary). The only evidence possibly relating to the ‘Jhone Collin’ of the graveslab, which the author was able to trace in Sussex Church Registers, was an entry in those of Rotherfield referring to a ‘Jone daughter of George Collyne’ buried 25th August 1549 at Rotherfield. It seems, however, more likely that the Jhone of the graveslab belonged to that branch of the Collins family which owned a forge at Burwash, together with Sockernsh furnace, in the parish of Brightling, in the sixteenth century (will dated 1535, Sussex Notes and Queries, vol. x, p. 9. Lewes, 1946-47; see also
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The method of casting was the same as with firebacks. Initially they were moulded from separate movable stamps; later from one-piece models. Use of the first method is noticeable on the above-mentioned gravelslab of Anne Foster of 1591. A late example is supplied by a gravelslab of 1619, at Burrington in Herefordshire. The coat-of-arms and each line of the inscription were moulded from separate boards pressed into the sand (see Pl. XXIII).

Railings

The use of cast iron for railings commenced in England in the early eighteenth century. The first on record are those enclosing the churchyard of St. Paul’s Cathedral in London. At the western end of the Cathedral, railings and gates have been removed and parts are now at Hastings (one gate) and at Lewes Castle. The total number of rails was over 2500, apart from 150 stronger members of similar profile at seven or eight-foot intervals. The total weight was above 200 tons. They came by ship to London in various consignments between September 1710 and June 1714, but it is not known where they were cast. Their production is generally attributed to Gloucester furnace at Lamberhurst, on the Sussex border of Kent but, according to local tradition, a part was cast at Ashburnham and at other furnaces in Sussex. The contract may have been subdivided.¹

Cast-iron railings of a similar type, designed in 1722–1730, were fixed round the Senate House at Cambridge, though these differ from the railings of St. Paul’s in that there is a bar of wrought iron between each pair of cast-iron balusters. About 1726, the church of St. Martin’s-in-the-Fields in London was enclosed with cast-iron railings. The use of cast iron for railings gradually increased in the course of the eighteenth century, when balconies for town houses came into fashion all over the country.²

CAST IRON FOR INDUSTRIAL, AGRICULTURAL, AND DOMESTIC USE

Cast-iron objects for industrial use were of a heavy type, such as hammers and anvils for the forge and the various plates for equipment of the hearths at finery and chafery. Their weights hardly changed until well into the eighteenth century, as is shown in the subsequent chapter on the forge. Plates of cast iron laid round the mouth of the furnace to protect the stonework are referred to first in 1591. Other heavy objects

² Gloag and Bridgewater, pp. 46–47, Figs. 42 and 43 (railings of Senate House, Cambridge) and 115–116.
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were cast quite early in the sixteenth century, such as hurstes used in the framework of the power hammer at the forge, gudgeons—i.e. centre-pins fixed in the two ends of the axle of the water wheel, and the pillows termed boites on which they rested; also buckstaves to support the timp stone at the furnace, and lintel beams for the front aperture.†
Weights were also cast at an early date.‡ Cast-iron moulds for casting smaller objects, mainly shot, are mentioned first in 1585.³

Cast-iron rollers for crushing sugar canes were sold and used in sets of three vertical rolls geared together and driven by oxen. They were made round and hollow like a drum, the hollows being filled with timber. First evidence of sugar cane rollers being produced in England is from 1663 at which date they were made at Renishaw in Derbyshire. Patterns and a packthread measure of the height and compass had been sent from London. In Sussex sugar rollers and garden rollers were cast at Socknesh furnace in the late autumn of 1671. The garden rollers had an average weight of 5½ cwt., and the sugar rollers a little over 3 cwt. Sugar cane rollers were sent to the Colonies, e.g., in 1674 to Barbados by Andrew Orgall, a West Indian merchant.⁴

Iron rollers for the rolling- and slitting-mills cast in England seem to have been of superior quality in the eighteenth century, for a broken roller had to be sent from France to London to be recast, work being held up until it was returned.⁵ Rails of cast iron to replace those of wood were produced by the Coalbrookdale Company in 1767.⁶

Cast-iron objects used in agriculture were many. Brand irons for marking cattle were cast at Panningside furnace, Sussex, in 1549. Casting of ploughshares is suggested by a 'share mould' bought in 1556 from an ironmonger in London for Robertsbridge. 'Wain bowkes', apparently bolts for keeping the wheel of the cart in position, were cast in considerable numbers at Parkend furnace in the Forest of Dean in 1653–57. An early instance of casting 'coppers' in iron is the iron

2 '3 halfe hundredth weythes of cast jeryn & one quarter weythe', inventory of Potmans forge, Sussex, of 1582, Ashburnham, Muniments No. 298.
3 Amongst old iron delivered to the forge at Attercliffe, near Sheffield, Yorkshire, 'IV cast moldes', account of 1585–86, Sheffield, Duke of Norfolk's estates office. A shot mould from Darvel furnace, Sussex, is at the Museum of Hastings.
6 Ashton, p. 134.
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‘furnace’ containing 20 gallons and cast at Ruabon furnace, Denbighshire, in 1706.¹

The most important articles for domestic use were pots and pans. Some pot founding started in Sussex almost immediately after gun founding had commenced at Buxted in 1543, for it was the Buxted founder Charles who was approached to send an iron pot to Robertsbridge to be used by a ‘plummer’ in 1548.² At Dyffryn furnace, Glamorgan, sixteen iron pots were found among the ‘household stuff’ of the founder Edward Cavell, a Sussex man, at the time of his death in 1578.³ Apparently they had been cast at the furnace which also produced shot. Pot founding continued in the Weald in the seventeenth century. In 1635, John Browne of Brenchley furnace, in Kent, obtained a patent for monopoly rights to cast iron pots, kettles, chimney backs, salt pans, pitch pans, and iron weights.⁴

All these articles were still very heavy at the beginning of the following century. For example the average weight of the pots which were shipped in 1715 from Bristol to north Lancashire, was 18⁴⁄₉ lb., that of kettles 18 lb., and of large pans 1 cwt. 72⁴⁄₉ lb.⁵

Production of small cast-iron ware such as the above increased in the first half of the century. At the two furnaces of Backbarrow and Leighton in north Lancashire, in which it had constituted not more than 1% of the total furnace output in 1713 to 1725, the production of particular cast-iron pots, kettles and pans, increased considerably in the twenties and thirties, so that in 1752 a total of 19,000 were cast from 190 tons of pig iron. This was mainly due to the work of Isaac Wilkinson, employed as a ‘pot founder’ until 1748. He appears to have introduced the casting of box irons for the smoothing of linen, for which he had obtained a patent in 1738 (Patent No. 565). He carried the metal from the furnace in large ladles to a cowshed, where it was poured into prepared moulds.⁶

The increasing demand for pots, kettles, and pans led to an improved method of casting them, in which dry-sand moulding in flasks or boxes was substituted for moulding with loam or clay. The inventor was Abraham Darby who on 18th April 1707 obtained a patent (No. 380) for ‘casting Iron-bellied Pots and Other Iron-bellied Ware in Sand only without Loam or Clay’. The bellied pot was a three-legged cauldron of largest diameter in the middle. It became the typical Darby product. The exact nature of Darby’s invention is not disclosed in the patent,

¹ 'caestyng of 1 ton of brandiron', Pe., No. 381(2), a 'share molde', Pe., No. 381(3) — PRO, SP 47, Inters. 11, vol. 190 and 1578 — A. Stanley Davies, 'The Early Iron Industry in North Wales', Newe. Tr., vol. xxxv, p. 87.
² Pe., No. 372(5).
³ PRO, Chancery Proceedings, Eliz. Al, No. 50.
⁴ PRO, SP 47, Charles I, vol. 264, fol. 154 — Straker, p. 163.
⁵ Barrow-in-Furness, Public Library, MS 186, fol. 375. 378, 384.
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but it may be assumed that he is to be credited with the introduction of the dry-sand moulding method in conjunction with the multiparted moulding boxes. Pure dry sand, instead of loam, was used, since it would not generate steam when the hot iron was poured into the mould, so that the mould would not be ruptured nor the casting spoiled by steam.¹

FOUNDRIES

Another innovation, introduced at about the same time, and to have far-reaching effects upon the later development of the iron industry, was the introduction of foundries. In the foundry, castings were not produced directly from the ore as in the blast furnace, but pig iron obtained from the furnace or old castings were melted down in a coal furnace. As foundries were independent of charcoal and the resources of mineral coal were abundant in the country, castings could be produced much more cheaply in the foundries.

Re-melting of pig iron in foundries commenced in the English iron industry from about 1702 onwards, in an improved form of reverberatory or air furnace, in which the iron did not come into immediate contact with the mineral coal, but only with the flames produced from it. The improvement of the furnace is attributed to a Dr. Edward Wright, a physician and chemist in London, who was greatly interested in the development of better methods for the smelting of lead. From 1696 he experimented extensively at a reverberatory furnace in north Wales with the smelting and refining of lead. When he was finally successful in 1701, a lead smelting works was erected with a furnace which was given the name of 'cupola'. It was the first time that this term was used and Wright was subsequently regarded as the inventor. The nature of this improved type developed from the reverberatory furnace, is not known. It is supposed that Abraham Darby used such a cupola furnace when he started iron founding in Bristol, before he went to Coalbrookdale.²

It took a long time for the cupola furnace to be generally accepted. It was tried at Backbarrow, but appears to have failed, and castings continued to be produced directly from the charcoal blast furnace without

² A similar patent (No. 1758), but for large castings such as 'cannon, fire engines, pipes and sugar rolls' was granted to the above-mentioned Isaac Wilkinson on 21st April 1758, printed by Dickinson, loc. cit., p. 57. The sand was mixed 'with a little horse or cow dung, or any other thing to make it porous'; the sand was dried and blackened with charcoal dust or black lead 'to make the same come off or part from the metal when cast'.

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re-melting the pigs in the cupola. The foundry trade remained small in the first half of the century. It only began to expand when a more powerful and more equal pressure of blast began to be used, such as was produced by the cast-iron blowing-cylinders introduced in 1768 at the Carron ironworks near Falkirk in Scotland, which later became celebrated for castings of all kinds, but particularly for a short kind of cannon called 'carronades'.

The benefits which the country had from its gradually increasing foundry trade are described by a Frenchman who in 1775 studied the improvements made in the English iron industry. These were, he pointed out in his report, a more solid and more perfected iron, from which were cast 'many things which are very costly when executed in wrought iron, such as balconies, balustrades, railings, gates, porches, and bars'. But what he valued most was the fact that 'during the twenty years which have elapsed since the English began to adopt this method of first smelting the iron ore with coke in a blast furnace and then passing the cast iron so obtained through a reverberatory furnace before casting cannon, not one cannon so made had burst aboard their ships'. This, he continued, could not be said about the French Navy, since such accidents were so common aboard French ships that 'our sailors fear the guns they are serving more than those of the enemies'.

Malleable cast iron

The process of making cast or pig iron malleable was effected by partial decarburisation achieved by fusion of the iron in contact with iron ore. In this way the carbon in the pig iron was partially burnt at the expense of the intermixed ore and escaped as carbonic oxide. The first invention of this process in England is ascribed to Prince Rupert, the son of the Elector Palatine and, by his mother, a grandson of James I of England. The ingenious prince, who is credited with various discoveries, lived in England after the Restoration of the Monarchy in 1660 until his death in 1682. In 1671 he was granted a patent, part of which is concerned with his invention of 'softening cast or melted iron so that it may be filed and wrought as forged iron is'.

In 1676 the use of the patent was conferred upon John Brown of Brenchley in Kent. It is, however, not known to what extent the invention was applied. It seems to have fallen into disuse after the Prince's

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2 Ashton, p. 51.
4 Percy, p. 802.
6 CRO, Lewes, *Archives of the Hutton family.*
The Casting Branch
dearth. The great French metallurgist Réaumur was well acquainted
with the process and described it in 1722. In England it was rediscovered
by Samuel Lucas in 1804, and soon afterwards put into practice at
CHAPTER XVI

THE FORGE

ORIGIN OF THE FINERY PROCESS AND EARLIEST EVIDENCE

As cast or pig iron from the furnace was too brittle to stand the force of the hammer, it had to be converted into malleable or wrought iron, before it could be sold to the smith for further working. This was effected in the forge, in which the pigs were first decarburised by oxidation, which eliminated the surplus of carbon and other impurities, acquired during the process of smelting in the blast furnace.¹

Possibly refining of iron originated from the process conducted in the bloomery. The crude bloom obtained from smelting in the bloom hearth was put into a second hearth, the string-hearth, in which it was purified to some degree by the action of the blast from impurities before it was consolidated by the hammer.² When water power was applied, it could happen that by an occasional increase of blast a portion of iron was liquefied to cast iron instead of remaining in the pasty state required by the operator. Although this would have been regarded at first as a waste product it is not unlikely that the early bloomers discovered the possibility of converting it into malleable iron by reheating in a strongly oxidising blast and thus decarburising it. Undoubtedly this discovery would have been facilitated by knowledge acquired from the much older copper industry, in which refining by oxidation constituted a separate stage in the process.³

Refining of iron was conducted by a great number of different methods. The most comprehensive work on the subject, written by Prof. Tunner, Director of the Mining School at Leoben in Austria in 1858, treats of fifteen different methods.⁴ The principal distinction was

¹ For the following, cf. above, Chapter 10 — See also H. R. Schubert, ‘Early Refining of Pig Iron in England’, *Necr. Tr.*, vol. xxviii, pp. 59-75.
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whether the whole process was conducted in one and the same hearth, or in two separate hearths. The process was confined to one hearth in the forges of the major part of Germany, in Austria and Italy, in nineteenth-century France, and in parts of Sweden. On the other hand, in Belgium, Luxembourg, in France before the nineteenth century, and in England, the process was conducted in two separate hearths. In one of these, in England termed 'finery', the pig was melted down and refined, i.e. converted into malleable iron. Subsequent re-heating for drawing out into bars was carried on in a separate hearth termed 'chafery'. The second of the two methods mentioned above is designated the 'Walloon' process. The term indicates the region whence it is supposed to have originated, i.e., south-west of Liège extending via Namur into the north of France.

The earliest evidence in England is supplied by an Ordnance Account of 1496–7 showing that at Newbridge, in Ashdown Forest, 'rough iron', i.e. pig iron, and 'wrought iron' were produced. Further, a quantity of 'rough iron fyned', i.e. pig iron that had been subjected to the process of refining, was bought by the King to be used for casting gun shot. The term 'fyned' was applied to the iron before it was delivered to the shot-founder, i.e., it was refined at the works and not afterwards by re-melting in further preparation for shot-founding. This is the first evidence in English history that the refining of pig iron was practised in the country.

THE BUILDINGS OF THE FORGE PLANT

In the inventory of Newbridge, Sussex, of 1509 (App. VI) the three essential parts of an English forge are indicated: finery, chafery, and hammer. They were all in one building and equipped with water wheels. The building of the early forge consisted of a wooden framework the interstices of which were boarded with planks of wood; the roof was tiled. The foundation walls however were of stone which was necessary because of the water conduits adjoining the building. Apart from those parts covered with cast-iron plates the floor of the forge was paved with tiles. The amount of wood composing the building was a potential danger and cases of destruction by fire were not infrequent. The

2 In 1548 a carpenter was paid 50s. for 'new framyng and coveryng the forge howse' at Robertsbridge, Sussex, Pe., 372A — 'Bordynge of the forge' in 1552 and 1556, Pe., No. 980(2) and 381(3) — For the building of a forge at Middleton, Warwickshire, about 1591, approximately 80 tons of wood were required, Middleton Papers — Cf. also the painting by Blès, Frontispiece.
3 Robertsbridge, 'river walle' at the forge referred to in 1559, Pe., No. 378(10).
4 5,000 'pavyng tylls' were bought for Robertsbridge forge in 1555, Pe., No. 381(2).
5 Whitecroft forge, north of Lydney in the Forest of Dean, erected in 1628–29, had to be rebuilt in 1632 because the lower part of the forge had been burnt down, App. XII.
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danger of fire probably explains why the wooden building was replaced later by one entirely of stone. The change however does not seem to have taken place earlier than about 1650.\(^1\) In any case, in the eighteenth century stone buildings became the rule.

The above-mentioned forge at Newbridge represents the smallest type of a complete forge, since it had only one finery apart from the chafery and hammer. This type still existed in Sussex as late as in the seventeenth century, e.g. at Frant in 1652.\(^2\) The majority of the forges in Britain however had two fineries, one chafery, and one power hammer.\(^3\) After 1600 when production increased, larger forges were erected in many places, with three fineries, a chafery, and two power hammers. Sometimes these were called ‘double’ forges.\(^4\) In the Royal ironworks in the Forest of Dean both types of forge were in existence. Of the five forges described in the inventory of 1635 (App. XII) three were of the new larger type, 70 feet in length and between 28 and 31 feet in width. The two smaller forges were 42 feet long and between 30 and 32 feet wide. The last-mentioned measurements may be taken as representing the type of forge buildings which prevailed in Britain.

Apart from the forges in which the whole process of refining pig iron and of consolidating and shaping the refined iron with the aid of a power hammer was concentrated in one establishment, there were small forges in which the two parts of the process were conducted separately in buildings sometimes a fair distance apart. In certain forges such as Bromley and Cradley in the Midlands there were only fineries producing blooms and occasionally anconies which were sent elsewhere to be drawn out into bars by a power hammer. Cradley forge was a finery from which the refined iron in the shape of blooms was sent to the forge at Lye situated farther down the Stour valley. Lye forge had no finery but a chafery for reheating the blooms and a power hammer for consolidating and finally shaping them into bars.\(^5\)

In addition to the forge building or forge house the establishment consisted of store houses and of dwelling houses for the workers. At Robertsbridge forge in 1542 which was the date of the first erection, a ‘coal house’ for the storage of charcoal was built mainly with wood at the total expense of £2 16s. 4d. There was also an ‘iron house’ with

\(^1\) Lydbrook forge, in the Forest of Dean, built about 1631 was still covered with wooden boards, App. XII. At the new forge of Brightling, Sussex, built in 1648 the ‘mason’s work’ was confined to the building of wheel race and fundaments whilst a carpenter made ‘the roof and body of the forge’, BM, Add. MS 33155, fol. 43v.

\(^2\) Inventory of 1652, Sussex AC, vol. xxxii, p. 29.

\(^3\) Early evidence of 1550 (Sheffield, Sussex), Arch. J., vol. 69, p. 288 — The eighteenth-century forges in the Stour valley, Worcestershire, still represented this type, Lewis, Knights, P. 91.

\(^4\) At Rievaulx, Yorkshire, first about 1613, Be., Nos. 459 and 331.

\(^5\) Inventory of 1724, Public Library at Dudley — Further evidence from Cheshire, Staffordshire, and Worcestershire around 1700 is supplied by Johnson, pp. 19a, 20, 82 — Cf. also App. XVI, section 16 (Pontypool, 1704).
front and back door for storage of the finished products. The two fencers and the hammerman had their separate houses. The other workers shared a common dwelling house. Store houses and dwelling houses and the houses of the clerk (i.e. the manager of the works), and the coal keeper are described with their measurements in the inventory of the Royal ironworks in the Forest of Dean compiled in 1635 (App. XII). The largest was a coal house of two storeys at Parkend forge. It was 62 feet long and 29 feet wide. The side walls were 17 feet high of which 5 feet were of stone and the rest of timber. It had five bays which may

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Fig. 32. The forge at Pontypool.

(A) forge; (B.C) coalhouses and sheds; (D) charcoal yard; (EE) part of the Grove grove intended to be enclosed; (FF) the Cynders bank; (G) the forge yard and stable. (1-7) houses of various tenants. Pontypool 20th October 1834. W. Llewelin.

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1 Pe., Nos. 371, 377(2), 379(2), 381(3) — A 'new house of the workmen to lie in at the forge' was built at Rievaulx in 1613-14. Ec., No. 459 — At the ironworks in the Forest of Worth, Sussex, '3 lytell howes for 2 fyners and one founder to dwell in' were built in 1547 at the total expense of 60s., *Arch.*, vol. 69, p. 303.

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have been sections for storage of charcoal according to its quality and date of production. Between this coal house and a second which was apparently disused, was a coal yard protected by an eight-foot high wall. A similar arrangement is shown on a map of the forge at Pontypool in Monmouthshire. Although the map is of a later date, it represents the outlay of the whole establishment as it was in the late seventeenth and eighteenth centuries.¹

The houses (1–7) marked on the map as let to tenants, apparently had formerly been the houses of the ironworkers. The largest (1) was probably the clerk’s. The plan of the forge house (A) shows the four water wheels, two at each side of the house. The wheels on one side supplied the two fineries with motive power, and those on the opposite side the chafery and the hammer. The hammer pond is not visible in its whole extension. Such ponds were very large. Even a small forge such as Bromley, in Staffordshire, erected about 1561, had a pond covering 3 to 4 acres.²

THE HEARTH

In respect of the structure and equipment of the hearth at finery and chafery hardly any details are available in literature earlier than the eighteenth century, apart from a brief statement made by Plot in 1686 referring to ‘open hearths’ commonly under the same roof, i.e. in one and the same building.³ Frequent items in accounts and inventories of the sixteenth and eighteenth centuries however make it possible to reconstruct the hearths of the early English forge.

Each hearth was surmounted by a huge chimney. The back and the adjoining side where the tuyere was, were closed in by walls. The two opposite sides were left open, so as to enable the forgersmen to work in the hearth.⁴ Above each of the two apertures a square bar was placed horizontally as a support for the chimney surmounting the hearth. The upright between the two apertures sometimes seems to have been a bar of wrought iron, e.g., at Robertsbridge, in Sussex.⁵

¹ The forge is referred to first in 1577, PRO, Exchequer Depositions by Commission, 22 Eliz., Trin. 4. It gained in importance during the following seventeenth century, A. A. Locke, The Hanbury Family, vol. i, pp. 148–149. London, 1916 — See also App. XVI (1704).
² PRO, Exchequer Special Commissions, No. 2098. The site of the forge is indicated by the present Forge farm on the north side of the river Blithe.
³ Plot, p. 163.
⁴ In 1555 ‘one load of stone to make the chafery chimney’, and in 1565 ‘new makinge and amendinge the stone walles of the chymnes’, at Robertsbridge, Pe., Nos. 378(31) and 381(2) — At Rievaulx in 1617 several references to ‘wallinge’ of the finery ‘backwall’, Be., No. 554 — In Blæs’s reproductions of the finery one aperture is depicted (see Frontispiece), but two in the illustrations in Diderot and D’Alembert’s Grande Encyclopédie of 1765, and also on Pehr Hilleström’s pictures of Walloon forges in Sweden (see Plate xxxv).
⁵ A bar for the chafery chimney 109 lb., Robertsbridge, 1568, Pe. 378(18) — In 1548 a finer at Robertsbridge was given an iron bar weighing 43 lb. ‘to be made mete and necessary for to bere [i.e. bear] up the forepart of his finery chimney’, Pe., No. 372A — See also Swedenborg, p. 73, Tab. iv.
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In England the chimneys were not entirely built of stone. The superstructure appears to have been made of wooden lathes fixed with nails to the four corner posts and daubed with a layer of mortar. Such an arrangement saved expense, as joiners and hammermen were enabled to do the repairs of their chimneys themselves: such repairs were a frequent item in all the early forge accounts.

The earliest documentary source supplying details of the equipment of the hearth at finery and chafery is an inventory of a forge in St. Leonards Forest in Sussex, of 1573, in which eight cast-iron plates for the two fineries are mentioned. In an inventory of Potmans forge, in Sussex, of 1582, in addition to the eight plates for the two fineries, plates 'in the pavements of the herthes' are referred to. In 1591, two bottom plates and eight other plates, all of cast iron, were cast at Rievaulx for the two fineries of the forge. In the same account two more plates are specified 'the one a bottom playt and the other a side finerie plaite'. The hearth proper or fireplace, i.e. the cavity in which the iron was re-melted and worked, was a square, with bottom and sides protected by cast-iron plates.

The number of five plates remained the same in many seventeenth-century forge inventories in the west and north of England and in Ireland. Apart from the plates protecting the bottom and the side walls of the fireplace, other plates not mentioned in these inventories were essential such as the plate covering the platform of the hearth at the rear of the fireplace (App. XV, A, f).

More details are supplied by two seventeenth-century inventories. One of these is not dated; it was attached to a lease whereby an unnamed forge was demised to one Henry Penfold. Presumably it was the forge at Mitchel park in the parish of Northchappell in Sussex. The

1 Robertbridge, in 1558, 'setting up a new tymbre chimney', Pe., No. 378(9) — A carpenter made the chafery chimney at the new building of Brightling forge in 1648, BM, Add. MS 33.155, fol. 45.

2 Robertbridge, in 1544, 'lathis made for the finery chimneys', Pe. 379(2) — Rievaulx, 1591–92, 'repairinge ryving of latt(es) and nauylinge them on the three chymleyes at the forge and nauylinge downe of bord(esi) and 'dawling all the three chimneys of the forge with morter', Be., No. 529 — The Flemish painter Martin van Valkenborch has depicted a similar superstructure, Évrard, Les Artifices, loc. cit., p. 57 (ab. 1535–1622).

3 App. IX.

4 Ashburnham, Sussex, Muniment No. 298.

5 Of the ten plates cast at Rievaulx in December 1591, four were designated as bottom plates in the account (App. X), but their number was corrected by the auditor to two. The weights of the various plates differed; two bottom plates 4 cwt. (i.e. 2 cwt. each), two other plates also 4 cwt., two more 4 cwt. 84 lb. and the last two 6 cwt. 28 lb. By their weights the last two may have been side plates, as on 1st March 1592 two plates with a total weight of 5 cwt. were cast of which one only was a bottom plate, i.e. of 2 cwt., so that the weight of the second was 3 cwt., Be., No. 529 — Cf. App. XV.

6 Inventory of the forge at Whitchurch, Monmouthshire, of 1633, Hereford Diocesan Registry, 1635–67, pp. 155 et seq. — App. XII (1635, Forest of Dean) — Inventory of the forge at Lisfinny, near Tallow, county Waterford, Ireland, of 1655 ('one sett of finnery Plates in number five'), Cork MS, vol. 28, No. 46.

7 Published by M. S. Guiseppi, in Surrey AC, vol. 18, pp. 50–52.
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forge was worked by Henry Penfold in the two years of 1637 and 1638, which suggests that the inventory was compiled when the lease commenced.\(^1\) The second, attached to a lease of 1666, is an inventory of a forge called Harsborne or Coldharbour Hammer on Thursley Heath, in Surrey. In a lease of 1610 this forge is described as being 'lately erected'.\(^2\)

In the two inventories the various plates of the hearth are enumerated, and, which is still more valuable, they are mentioned by their particular names indicating their position in the hearth and their function. This makes it possible to reconstruct the hearth and to supply a detailed description.

At the finery hearth (see App. XV, A) the bottom of the fireplace was covered by a 'bottom plate' (a). A 'fore plate' (b) was in the front where the finer worked. On its left toward the tuyere side, there was a hole in the wall (c) formed by the eye of a hammer,\(^3\) to let out the superfluous 'sinder' or slag. The 'tuyeres plate' (d) was on the side at which the tuyere (e) protruded into the hearth. The back plate (f) was termed 'hare plate'\(^4\) and the plate opposite the tuyere plate was termed 'fore spirit plate' (g) as it received the blast from the tuyere.\(^5\)

All these terms were applied in the Midlands also, except 'back plate' for 'hare plate'.\(^6\) The bottom plate (a) was not quite horizontal but slightly inclined towards the fore spirit plate (g). By this arrangement the superfluous cinder which rose to the top, could be tapped off without extracting particles of iron which collected at the deepest part of the hearth. The slope was achieved by placing small pieces of iron underneath the angles of the bottom plate. Very early evidence, probably the earliest in history, is supplied by an account of 1581, at which date a finer at the forge of Rievaulx in Yorkshire forged such a piece of iron.\(^7\)

The cavity thus formed underneath the bottom plate also made it possible to keep the plate cool either by air-current or by a current of water running underneath. Perhaps it is significant that the earliest evidence of such a contrivance comes from the north of England where,

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\(^1\) Mitchell park was parcel of the Earl of Northumberland's Manor of Petworth. Court Books and Account Rolls of the Manor are in possession of Lord Leconfield at Petworth House, Sussex, who very kindly permitted researches in his documents.


\(^3\) Lower Finery at Horsbame Hammer, 'one eye of a hammer at the sinder hole'.

\(^4\) The term 'hare' was derived from French 'aire' which was applied to the back plate in France, Gille, p. 95, and Percy, p. 602. In the Walloon finery in Sweden the term 'hären' denoting the same French origin, was applied, Swen Rinman, Förskick till Järnets Historie, Stockholm, 1782, translated into German by C. J. B. Karsten, vol. i, p. 563. Liegnitz, 1814.

\(^5\) 'Spirit' also is of French origin (esprit) meaning a movement of air, a wind; it was still used in this sense by the poet Shelley, in 1820. J. A. H. Murray, New English Dictionary, vol. ix, Pt. 1, p. 618. Oxford, 1908.

\(^6\) According to Dud Dudley, Metallum Mars, p. 32, London, 1665, these terms were 'so common among Forgemen ..., as is nothing more common'.

\(^7\) 'One rownde bar ende to make a stocke to hold uppe the plate lyenge upon thawer fynerye harthe', i.e. the hearth of the Low Finery, Be., No. 548.
XXII Cast-iron firedog ascribed to Ralph Hogge.

XXIII Graveslab of Robert Steward, 1619. Photo kindly supplied by Miss M. Wright, Hereford.
XXIV  Interior of the Walloon forge at Forsmark in Sweden, in 1793, by Peer Hillestrom.
By courtesy of Jernkontoret, Stockholm.
at a later date, the so-called 'Lancashire' hearth with its cast-iron water box for keeping the hearth-bottom cool, was invented. In respect of other countries such as France, Germany, and Sweden, there is no evidence of any such device before the late eighteenth century.  

Most of the side plates were inclined, the slant being adjustable according to the amount of heat which was to be generated.  

The possibility of influencing the work at the finery by the slant of the plates was well-known in the Midlands in seventeenth-century England. Dud Dudley referring to it, stated that by altering the plates (i.e. their position) either a larger quantity or a better quality could be obtained.  

By setting the work 'transhaw or transiring from the blast', the iron was 'lesse fined, more to the Masters profit', i.e. a greater quantity was obtained at the expense of quality. The reverse was achieved by making a 'Burrow work'. Dudley's statement mainly applied to the position of the tuyere plate. By making it 'transiring', or leaning slightly outwards (as Rinman worded it) the melting part of the pig was less exposed to air-blast and less oxidised. On the other hand, slanting it towards the interior, brought tuyere and blast closer to the melting pig and greater oxidation was achieved. Apart from England, the latter position for the tuyere plate was preferred in the Walloon country, as also mostly in France and Germany, in order to obtain a temperature sufficiently high to melt grey pig iron.  

In the two seventeenth-century inventories two fore spirit plates and two hare plates are also listed. Apparently the two fore spirit plates (g) were placed as in France where they frequently consisted of two pieces, one supported upon the other, forming an obtuse angle.  

Generally the hare plate (f) was fixed vertically against the back wall, and a second plate on the top of this wall. A plate in such a position occurred in the early fineries. It was intended to retain small particles of slag raised by the flame, and prevent them from falling back into the hearth, and in those fineries in which the pig was pushed forward from the rear of the hearth, it also served as a platform for the pig.  

The fore plate (b) against the side of the front wall generally inclined a little outwards, to facilitate the withdrawal of the refined ball from the hearth. There was often another plate (h) on the front wall. This was

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1 Percy, p. 603 (Franche-Comté process) — J. A. Cramer, Anfangsgründe der Metallurgie, vol. 2, p. 155. Blankenburg und Quedlinburg, 1775 (Germany) — S. Rinman, loc. cit., vol. 1, p. 561 (Sweden); it is of great interest that the cast-iron water box was known in Sweden when Rinman wrote, i.e. in 1782.  
2 E.g., in the Swedish Walloon hearth, S. Rinman, loc. cit., vol. 1, p. 566.  
3 Dud Dudley, loc. cit., p. 31.  
4 Percy, p. 603.  
5 Beck, vol. ii, p. 228.  
6 Such a plate is referred to in the description of the finery at Millom, in Cumberland, Swedenborg, p. 159. Position and use are absolutely in keeping with the original French term 'aire', which was derived from Latin 'area' and meant a resting place for the pig, J. O. Keirbridge, Technical Dictionary, vol. 1, p. 15.

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the ‘work plate’ which held the finer’s implements ready to his hand. This may have been the ‘fulling plate’ referred to in the two inventories.

The dimensions of hearth and fireplace are not mentioned in the early English literature on refining. The first to supply details was Swedenborg in 1734. His description of the English finery hardly differs from that of the Yorkshire ironmaster Pashley, given about thirty years later. The dimensions conform with those of the hearth in the Walloon country.¹

Hearth and fireplace of the chafery (App. XV, B) were of slightly different dimensions from those of the finery. The fireplace was somewhat larger and deeper, and, in particular, more elongated towards the rear of the hearth.² The cast-iron plates were much the same, but even here there is some difference, in that according to the two seventeenth-century inventories from Sussex referred to above, there was no second hare plate because no pigs were introduced from the rear as in the finery. The stone platform of the hearth at the side opposite the tuyere wall was covered with a large plate of cast iron (h). On the tuyere side two plates (dd) protected wall and tuyere from the effect of the greater heat generated in the chafery. By the early eighteenth century the number of plates lining the hearth of the chafery appears to have increased, in any case in the Midlands if not elsewhere. At Lye forge in the Stour valley, Worcestershire, eleven plates in the chafery hearth with a total weight of 22 cwt. are referred to in 1724.³

THE POWER HAMMER

The hammer generally used in Britain from the sixteenth to the early eighteenth century was a helve- or tilt-hammer.⁴ The helve or shaft was about 8 or 9 feet long and 30 or 40 inches in circumference. It was made of stout wood and clamped at intervals with iron hoops. The hammerhead (A) through which the shaft passed was made of cast iron. At the opposite extremity the shaft passed through, and was fastened with wedges into a cast-iron collar called the hurst.⁵ The pivots of the hurst

¹ Swedenborg, p. 159 — App. XVIII (Pashley) — J. Yeamans, La Métallurgie liégeoise, p. 27. Liège, 1939 — The dimensions are given in App. XV, A.
² The existing descriptions coincide in this respect, viz. Swedenborg (p. 159) in 1734, Pashley about 1760 (App. XVIII), and the article on ‘Iron’ in Pantologia, vol. vi, London, 1815.
³ Inventory of 1724, Dudley Public Library.
⁵ Hammer hursts of cast iron are referred to as being cast as early as 1554 at the furnace of Darfield, in Sussex, Pe., No. 331. Their weights remained pretty constant from the sixteenth to the late eighteenth century, i.e. 1 cwt. 28 lb., Be., No. 539 (Rievaulx, 1591), 1½ cwt. in Ireland, cast at Kilmackee in 1623 and 1624, but one of 1 cwt. (Cork MS, vols. 209, 419, 257), Fuller MSS at Battle (1½ cwt. at Heathfield, Sussex, 1729, 1746, 1770). At Lye forge, east of Stourbridge in Worcestershire, it was 1 cwt. 70 lb. in 1724 (Inventory, Public Library at Dudley).
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constituted an axis for the hammer, and worked horizontally between the limbs of the support (B). Above the hammer helve or shaft, a strong but elastic spring board of timber termed a ‘rabbet’ (C) ran parallel to the shaft. It was bolted firmly to a post (D) and also to the frame B through which it passed. The top extremities of the frame embraced a beam, generally called a drome-beam (from the French ‘drosme’).

The motion of the water wheel caused the axle-tree (E) to revolve, and with it a ponderous circular frame called the arm-case (F). In the arm-case were several knobs or blocks of wood shod with iron on their acting surfaces. Each of these knobs in turn lifted the hammer and

![Diagram of a hammer worked by a water wheel](image)

**Fig. 33.** Hammer worked by water wheel.
From Straker, p. 87.

jerked it against the rabbet. The hammer then fell upon the anvil (G) by its own weight. The force of the fall was increased by the compressed energy in the rabbet. The velocity of the fall was proportioned to that of the water wheel and the circumference of the arm-case. Figures illustrating the velocity are available from the late eighteenth century, but not earlier. The forge hammers used at Cramond near Edinburgh made 120 to 160 strokes a minute.\(^1\) As the weight of these hammers

\(^1\) The Statistical Account of Scotland, vol. 1, p. 213. Edinburgh, 1791. — For comparison, it may be mentioned that at a French forge of the late eighteenth century the hammer rose and fell up to 128 times a minute, Gille, p. 96 — Re Weights of hammers and anvils, see p. 262, note 4.
The Forge

was the same as that of the hammers used in England from the sixteenth century onwards, it may safely be assumed that the velocity was also the same. For its better preservation the hammer when it got hot was cooled with water, and probably the anvil too. Nevertheless, neither lasted long, and the same applies to the wooden beams such as the helve or shaft and the rabet. The weights of hammers and anvils remained fairly constant during the sixteenth and seventeenth centuries, though they increased in the eighteenth, apparently first in the Forest of Dean and the Midlands, and in the second half of the century in Sussex also. This indicates that the whole device hardly altered in the course of nearly two centuries since its first introduction in the 1490's.

THE PROCESS

One of the earliest descriptions of the process is contained in a Latin poem called 'Ferraria', of 1517 by Nicolaus Bourbon. The poet describes the operations conducted in the furnace and forge of Venduevre, near Troyes, in Champagne, of which his father was the clerk (i.e. manager). The account of the operations in the forge is as follows: As the metallic mass from the furnace cannot be called true, i.e. pure iron (germanum ferrum), a workman remelts (recoquet) and purifies

1 At Rievaulx forge 'a skeele [i.e. a wooden bucket] to water the hamre' is referred to in 1641, Be., No. 539.
3 For the forge at Robertsbridge, in Sussex, a carpenter made new rabbets in February and in November 1552, and new helves in September and November of the same year, Pe., No. 380(2).
4 It is difficult to ascertain the exact weights of the cast-iron hammer-heads and anvils, as the various accounts usually only give the total weight of both.

Hammer: cast at Rievaulx, Yorkshire, 4 cwt. 42 lb. and 5 cwt. each, in 1591 and 1592 (Be., Nos. 329 and 530); cast at Tanfield, Yorkshire, of the same weight in 1616 (Be., No. 532); In South Ireland one at 5 cwt. in 1623, all others at 5 1/2 cwt. each in 1623 to 1624, cast at Kilmackeoe furnace (Cork MS, vol. xiv, passim) — Tintern forge, four hammers cast at Halesowen furnace in Shropshire, 5 cwt. each in 1672-73; at Wildon forge, Worcestershire, 6 cwt. each in 1672-93 (evidence kindly supplied by B. L. G. Johnson, M.A., Birmingham University) — In 1717-18, cast in the furnaces of the Forest of Dean, varying from 5 cwt. 41 lb. to 5 1/2 cwt. each (PRO, Audit Office, Accounts various, No. 1243(5)) — In Sussex, cast at Heathfield furnace, varying from 4 to 4 1/2 cwt. each in 1736-70 (Fuller MSS, Battle) — In Scotland the weight was still from 4 to 6 cwt. in the 1790's, Statistical Account, loc. cit., vols. 1, pp. 213 and x, p. 450.

Anvil: cast at Rievaulx, 53 cwt. each, in 1591 and 1592 (Be., No. 529); cast at Tanfield 5 1/2 cwt. in 1616 (Be., No. 532) — Cast at Capoquin furnace, in south Ireland, 5 1/2 cwt. in 1621 (Cork MS, XII, 11) — Cast at Heathfield, Sussex, 1729-43, mainly 5 cwt. each, in 1736 three (in addition) at 4 1/2 cwt. each, in 1746 and 1770 at 5 1/2 cwt. each, but in 1768-70 five at 7 cwt. each — In the Forest of Dean, the last mentioned higher weight was achieved already in 1717-18 and even exceeded, i.e. 7 cwt. 42 lb. and 7 cwt. 102-103 lb. each (PRO, loc. cit.). At the same date, a forge anvil of 8 1/2 cwt. 15 lb. was cast at Leighton, Lancashire. Barrow-in-Furness Public Library, MS Z188.

9 See above p. 230.
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it a second time in a huge furnace and makes the mass of flexible (i.e. spongy) iron into balls (faciatque plicatile ferrum congestum in globulos): Up to this point the poet’s brief description is of the operation conducted in the finery which because of its large chimney, he says, looked like a huge furnace. Then he describes the reheating by different workers (i.e., the hammermen in the chafery) and the consolidating by a water hammer and forging into bars. Despite its brevity, Bourbon’s poem describes the main points of the Walloon process as conducted in France in his day, and his description conforms with the essentials of Réaumur’s much more detailed description of 1722.¹ As the blast furnace and subsequent refining had been brought into England from France, Bourbon’s account may safely be applied to refining as conducted in the early English forges.

It is not till the late seventeenth century that we get a description of the refinery process by English writers. The earliest is supplied by John Ray, the well-known naturalist, and represents the practice in Sussex, about 1674. The second, based on the practice in the Forest of Dean, is given by Henry Powle, in 1678. The third account, from 1686, is by Robert Plot and refers to Staffordshire.² All three supplement one another in many details, but at the same time there are discrepancies. The general impression is that the three writers were more interested in the procedure of hammering than in that of refining. They are extraordinarily brief regarding the construction of the hearth, the melting down of the pig iron, and the refining proper. Anyhow, as none of them was an ironmaster, they cannot be expected to have known all about the process of refining, which to some extent depended upon the skill of the individual worker, who kept the details secret. As late as in the eighteenth century refining was considered to be ‘the most difficult operation in all metallurgy’.³

To obtain a better idea of the hearth and the process involved, the three reports may be supplemented by evidence from original iron-accounts and inventories of forges dating from the sixteenth century onwards and also by two eighteenth-century descriptions of the English finery process. The first of these comes from Emanuel Swedenborg, the well-known Swedish philosopher and scientist, in his Treatise on Iron published in 1734.⁴ The second was written in about 1760 by a Yorkshire ironmaster by the name of Pashley.⁵ Lastly, an article on iron in an English encyclopaedia of 1813 is useful as much of the process

³ 'Die schwereste Operation in der ganzen Metallurgie', J. A. Cramer, loc. cit., vol. 11, p. 154-
⁴ Swedenborg, pp. 159–160: 'Officinae et socii ferrarii Angliae.'
⁵ App. XVIII.
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remained unaltered at that date. In this way it is possible to reconstruct the process of refining as it was conducted in England from about A.D. 1500 to about 1800.

The picture by the Swedish artist Peer Hilleström (see Pl. XXIV) briefly illustrates the whole process conducted in a forge of the Walloon type, from refining in the finery (right) to reheating in the chafery and drawing out the iron by the power hammer (left).

The operation in the English finery proceeded in several stages; melting down the pig, refining proper, and lastly working the refined iron into a lump or ball generally termed a ‘bloom’.

First the bottom and sides of the fireplace were lined with charcoal dust, obtained by passing the coals through a sieve. The finer the dust, the better. Then the fireplace was filled with charcoal and the pig put into a position suitable for gradual smelting. The end to be smelted was first covered with charcoal, and placed slanting slightly downwards towards the tuyere. The plate on which the pig rested was in the English finery the back or hare plate, to judge by the available evidence. Then the fire was lighted, the blast turned on, and the pig gradually pushed forward over wooden rollers. Exposed to a strongly oxidising air-blast, the iron went into fusion and trickled down in drops.

Immediately after fusion of the first portions the finer commenced ‘stirring and working’ with ‘long iron bars’ as Powle worded it in 1678; the bars generally were termed ‘ringers’. Operating with the ringer kept the whole melting matter in a fluctuating motion and prevented from as much as possible particles of pig-iron, without melting properly, dropping to the bottom of the hearth and remaining there. A ringer was also used to clean bottom and sides of the hearth and particularly the tuyere from melted matters which concreted on them; it made them rise to the top where they melted and deposited their iron. Portions adhering to the ringer during this operation were loosened by giving the end that was outside the fire a few strokes with a small hammer. Such working with ringers continued throughout the whole process of

3 *Pantologia*, vol. vi, London, 1813.
4 *riddling braies*, i.e. small coals at the forge of Rievaulx in 1642, Be., No. 539. At the finery of Backbarrow forge, Lancashire, ‘riddling coals’ kept three men occupied in 1715, one of them for 3½ weeks, Barrow-in-Furness, Public Library, MS Z186, fol. 322a.
5 *Phil. Tr.,* vol. xvi, p. 934 (Forest of Dean, 1678, placing the pigs ‘behind the fire’) — Swedenborg, p. 159 (forge at Millum, Cumberland, 1734) — In one of Henri Blès’ industrial paintings now in the Johannez in Graz, Austria, the pig is depicted also as being moved from the aperture at the backwall, Évrard, *Les Artistes*, Fig. 17, p. 39.
6 At Rievaulx forge ‘wood for rollers’ in 1616 and again in 1625, Be., Nos. 534 and 536. Derived from French ‘ringard’; the term first occurred in the inventory of the finery at Newbridge in Sussex in 1509 (‘a rangard of iron’), App. VI. Forge ringers varied in weight between 22 and 28 lb. in the sixteenth century. Accounts of Rievaulx forge from 1577 to 1591, and also in 1637, Be., Nos. 527–529, 538.
7 In 1591, ‘one hammer for beating of synders of ther [their, i.e. the finers’] ringer weinge III lb.’ was made at Rievaulx forge, Be., No. 539.

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refining. During the operation of melting, the pig iron was decarburised to a great extent. At the bottom of the hearth where the temperature was lower, the metal solidified into a semi-solid state. The cinder (slag) which separated during this operation constituted a slag-bath which was kept in the hearth, apart from the superfluitly tapped off when the cinder floating on the surface reached the level of the slag-hole.

After the first fusion, refining proper commenced. The semi-solid mass was broken up. With an iron cross-bar called a ‘furgon’ or ‘four-geon’¹ those portions that were not yet sufficiently decarburised, were raised towards the tuyere. They were turned upside down and then sideways,² so that all parts were exposed to the action of the blast. If necessary the operation was repeated until all parts were sufficiently refined.

After the second fusion the last part of the process commenced. The whole of the metallic mass was raised once again from the bottom. It was held in front of the tuyere, in order to expose new surfaces to the blast which was considerably increased at that stage. The metal melted down a third time and formed pasty lumps at the bottom which were left for some time in the slag-bath. Then the finer gathered the lumps and kneaded them into a ball termed a ‘bloom’ or ‘loop’ (from French ‘loup’). The bloom was a spongy mass of malleable iron the interstices of which were filled with slag (cinder).

The whole process of melting, refining and balling took one hour.³ Success was judged by sounding the metallic mass with a ringer. At first particles of slag and iron adhered tightly to it and had to be knocked off with a hammer. As soon as they began to adhere less, the finer knew that the metal had begun to change into malleable iron, or, to use a phrase commonly used by the early finers, had ‘come to nature’. Further indications were changes in the slag and in the colour of the sparks. These were bright red at first. When they changed to white the finer stopped the slag-hole, so that the cinder should be retained as a slag-bath which was considered ‘conducive to the conversion of the iron’.⁴

The early English finers were well aware of the effect slag or cinder had upon the iron. For example, when investigations were made about a trial of iron which had taken place at Shipley near Bradford in Yorkshire in 1591, one of the questions was whether the cinder which adhered to the iron bar used for stirring, was beaten off ‘upon the iron’.

¹ A term of French origin which like ‘ringer’ is in all the inventories from 1509 onwards. The weight was smaller than that of the ringer, and generally 15 lb. Two at Rievaulx (1591–1615), Be., Nos. 529–531, but 20 lb. in 1637, Be., No. 538.
² G. Boate who obtained his knowledge from English ironmasters in Ireland where furnace and refining had been introduced from England, commented on this operation by saying ‘the Finer turning the melted stuff to and fro’. Boate, p. 140.
³ Plot, p. 163 (1686), confirmed by Swedenborg, p. 159.
Hammer slag which contributed to complete decarbonisation and purification by the oxygen of the protoxide of iron, of which the slag chiefly consists, was also known.¹

The preceding description of the process applies to the refining of grey cast iron which has a melting point of 1200° C to 1250° C. White cast iron required a different treatment. It melted more easily, but in a state of fusion it was less liquid and congealed more promptly. For this reason it was necessary to prevent the fusion from taking place too rapidly, and to retard coagulation, otherwise the iron would go down to the bottom and congeal without being sufficiently decarburised and purified. In order to avoid such an undesirable effect, precautionary measures were taken. The tuyere plate was fixed vertical instead of reclining, so that the pig was less exposed to the blast. The intensity of the blast was slightly diminished during the whole process. As a result the iron did not melt drop by drop like grey cast iron, but in little scales, nor did it become completely liquid. The depth of the fireplace was diminished, so that the mass of iron was kept in a pasty state during the process. A smaller quantity of rich slag was added, in order to achieve a more gradual decarbonisation. By these means, the process was prolonged which required a greater consumption of fuel.²

After the ball had been made, it was taken out of the hearth with great tongs termed 'mordens' which were clasped and held tight by iron clamps.³ Then it was beaten with a sledge-hammer on an iron plate a little distance from the hearth, to remove the external crust of charcoal and slag, and then dragged with iron tongs along an iron-paved path to the great water hammer. There, first with gentle strokes then with stronger, a fair amount of slag was forced out and the ball was consolidated into a thick square, about two feet long. This operation was called 'shingling the loop' (from the French 'cinglage').⁴ As in England the bloom or loop was comparatively small, the term 'half-bloom' was sometimes applied to it.⁵

The bloom was returned to the finery hearth, in order to receive the first welding heat whereby a considerable proportion of impurities was 'sweated' out. Application of the first welding heat in the finery hearth was one of the main characteristics of the Walloon process as

¹ PRO, Essexque Depositions by Commission, 35/6 Eliz., Merch. 34. — 'A hamsla rake', inventory of 1582, Ashburnham, Muniment No. 298. — 'Hamsla' or 'hamslowe' was used for refining at Rievaulx in 1624–25, Be., No. 536. — See also Percy, pp. 605–606.
³ Small mordens from 7 to 15 lb. in weight, and great mordens from 41 to 50 lb. from 1581 to 1637 at Rievaulx forge, Be., Nos. 526, 529, 530; 'clames', Be., No. 530 (1592). — Morden and Clam are shown in Plate xxiv (third man—in the centre of the picture—working at the chafery).
⁴ A plate to bete the lope uppon at the fynerye', inventory of 1582, Ashburnham, Muniment No. 298. — See also Ray (1674), p. 136.
⁵ Plot, p. 163, and also Pastley (App. XVIII). Ray and Powle used the term 'bloom' only.
conducted in England, France, and Sweden.\textsuperscript{1} The object was to save fuel, and at the same time to increase the volume of the slag in the hearth. During this heating, which took one hour, a new pig was launched into the hearth, and repetition of the process commenced. The bloom when taken out of the finery hearth was forged with the water hammer into an ‘ancony’.\textsuperscript{2} This was an elongated piece the middle of which, about 3 foot long, was forged into the shape of the bar. A thick knob was left unfinished at each end, one being smaller than the other. By the forging of the centre piece the slag in the iron was driven towards the ends.

The remainder of the process was conducted in the chafery with intermittent hammering. In its hearth the smaller of the two unfinished ends of the ancony was heated for a quarter of an hour, and then consolidated by the power hammer and forged into the shape of the middle. The thicker end, the ‘Mocket head’, required two heatings in the chafery before it was finally drawn out into the shape of the bar.\textsuperscript{3}

As the hardest and most carbonaceous particles were still in the iron after it had left the finery, a higher temperature (a white or welding heat around 1400° C) was required for sweating them out. The temperature was generated by a stronger blast produced by bellows larger than those at the finery.\textsuperscript{4} The heated iron was consolidated by the power hammer, and forged into the final shape of the bar, the rough ends of which were cut off by chisels.

Although the bars varied in weight and size, there was a certain standard to which the bars produced for sale in the sixteenth and seventeenth centuries conformed more or less. Two sorts of bar can be distinguished, ‘long squares’ and ‘small squares’, the former being 9 to 13 feet in length and weighing about 40 lb. on the average. The ‘small squares’ were different in thickness (one inch square in section as a maximum), and accordingly in weight (one seventh less). The bars normally produced for sale were the long squares. In 1630, e.g., the hammermen at Richard Boyle’s Irish forges at Kilmackoe and Lisfinny threatened to give notice, if they were compelled to make small squares, because the ‘beating out so thin and light’ not only was more difficult

\begin{tabular}{llllll}
& ft. in. & ft. in. & ft. in. & ft. in. \\
Finery, & 6 & 6 & long, & 2 & 6 & wide \\
Chafery, & 6 & 6 & long, & 2 & 9 & wide \\
\hline
Finery, & 6 & 10 & long, & 2 & 5 & wide \\
Chafery, & 9 & 9 & long, & 2 & 10 & wide
\end{tabular}

\textsuperscript{1} Réaumur, loc. cit., p. 245 — Tunner, loc. cit., vol. ii, p. 156 — Percy, p. 600.
\textsuperscript{2} Plot, p. 163. The term was derived from French ‘encrenée’ which meant ‘notched’, ‘indented’.
\textsuperscript{3} Derived from French ‘maquette’ which meant a bloom. See also Plot, p. 163.
\textsuperscript{4} Swedenborg, p. 159, referring to the chafery at Millum, Cumberland: ‘Folles hic sunt longiores’ — Size of bellows.

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but took longer and consumed more coal than the forging of the long squares which they called 'ordinary' iron.1

Stronger and heavier bars such as those required as supports in buildings, were made by doubling. This was performed either by breaking an ordinary bar through the centre, doubling it back on itself, and reforging it, or by piling together several bars and forging them into one. For this a welding heat of about 1400° C was required. Spanish iron was preferred for 'all great works, that require Welding', such as 'thick strong bars'.2

A sideline which required high temperatures, was producing bars from scrap metal, a small amount of which was worked up in the forges. It generally consisted of broken hammers, firebacks, forge-plates, anvils, and rejected sows of pig iron, many of which were collected from the cinder or slag heaps of the furnaces at which they had been dumped.3 Scrap iron was sometimes obtained from very distant ironworks.4 The amount of slag and impurities contained in pieces of pig iron from the slag heap is indicated by the unusually great loss (almost half) incurred in the process of converting it into malleable iron.5 The hardest slag was found in the 'bears' which sometimes conglomerated in the hearth of the blast furnace.6 The treatment of iron which because of its hardness could not be dealt with in the ordinary way, was a difficult work which required more heating and hammering than usual.7 Much of it was performed by the hammerman at the chafery but finers also

1 Cork MS 78, p. 181, and vol. 16, No. 158. See also vol. 1, No. 123 (fourteen bars in the store house in Cork, in 1604, with an average weight of 414 lb.); vol. 2, No. 79 (40 lb. in 1607); Grosart, first series, vol. 1, p. 243 (1675 'whole bars' weighing 30 tons sent to Bristol, in 1620) and vol. II, p. 285 (sent to London, in 1628); Cork MS, vol. 29, No. 68 (1639); iron delivered from Ulster to London 40 lb. per bar (contract of 1641, Leicester, Museum).

An average weight of about 40 lb. can also be deduced from sixteenth-century accounts (e.g. two bars with a total weight of 73 lb. made at Robertsbridge in 1543, Pe., No. 379(1); a 'square bar' for the furney chimney at Rievaulx in 1578 weighed 40 lb. Bo., No. 527).

2 J. Moxon, Mechanick Exercises, No. 1, p. 9. London, 1677 — A bar made in 1568 as a support for the chafery chimney at Robertsbridge had a weight of 109 lb., Pe., No. 381(b) and 376(18) — In 1668, an iron merchant of Bristol ordered 30 tons from Richard Boyle's Irish forges of which one half should be 'drawn into Spanish square turned doble', and the other half 'flatte', Cork MS, vol. 2, No. 134.

3 At Rievaulx the amount was approximately 7% of the total output of the forge in 1622, Be., No. 535 — 1547-48, 'fyning of broken hammers' at Sheffield, Sussex, PRO, Exchequer Various Accounts, Bundle 493, No. 19 — 1559, 'fyndinge 371 gonstones' (i.e. refining 371 old bullets) laid up in the storehouse at Robertsbridge, Sussex, Pe., No. 378(10) — 1581, 'gathered out of the synderhill', at Rievaulx, Be., No. 528.

4 1615-16, bar iron was made out of forty 'olde Sussex hammers' at Rievaulx, Be., No. 533 — Scrap iron from Sussex, Holland, Dantziz and Sweden, 1710 et seq., Nave. Tr., vol. xix, pp. 70-71; (south Yorkshire).

5 1615-16, 'refinyng and drawing forth of XVI cws.' from 31 cws. of 'rough yron gathered out of cindres', Be., No. 539.

6 1591, refining of 'one sowe which did sincke into the hearth and was taken forth of the furnace bottom', at Rievaulx, Be., No. 529.

7 At a trial made at Chelsea in 1731, pig iron made with mineral coal required fourteen heats in the chafery instead of the usual three of four, Gentleman's Magazine, vol. 1, p. 167.

London, 1737.
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were engaged in it. Because of the laborious work which required much skill, both were paid double wages in accordance with the custom of the country.  

The process conducted in the forge remained essentially the same almost to the end of the eighteenth century, when changes began with the introduction of Cort's process of rolling and puddling, patented in 1783 and 1784. One important innovation, however, was of an earlier date. This was the so-called 'Lancashire' hearth, the main characteristic of which was a cast-iron water box placed underneath the bottom plate. The date of the innovation is obscure. That it was early in the eighteenth century is indicated by a rather vague reference in connection with the fineries of the Backbarrow Company in Lancashire built in 1711 and first worked by finers from Staffordshire. In any case the cast-iron water box was invented before 1782 when it was known to the Swedish metallurgist Rinman. The invention was facilitated by a device consisting in a cavity underneath the bottom plate, the earliest evidence of which is of 1581 in connection with the forge at Rievaulx.

PRODUCTION

The various implements used in the forge, and the iron parts laid in the chimneys, were made and repaired by the workers themselves. The forging was done by hand on an anvil smaller than the one that served the power hammer. Refined blooms, greatly varying in weight, were used for the forging. Small tools were made from half blooms, produced by dividing blooms with a hatchet.

The annual output of bar iron largely depended upon the supply of pig iron from the furnaces. At Robertsbridge in Sussex the average output was 129 tons from 1542 to 1573. It was greatest in the first seven years (an average of 139 tons) as it was then supplied with pig

1 In 1627, Harman Brisbye, hammerman at Rievaulx forge, was paid for 'drawinge 13 cws. of bar iron out of old broken iron'; in 1641 'melting half a boyled sowe at the chafery', Be., Nos. 538 and 539.
2 Bromley, Staffordshire, in 1575, Stafford, Wm. Salt Library D1734 — Rievaulx, in 1578, 'according to custome in other works', Be., No. 547.
3 A. Fell, pp. 248, 250. See also above p. 278.
4 Percy, p. 603 (Franche-Comté process). J. A. Cramer, Anfanggründe der Metallurgie, vol. ii, p. 155. Blankenburg und Quedlinburg, 1775 (Germany). — S. Rinman, loc. cit., vol. i, p. 621 (Sweden); it is of great interest that the cast-iron water box was known in Sweden when Rinman wrote, i.e. in 1782.
5 'One rownde bar ende to make a stocke to hold uppe the plate lyenge upon thawer synerye harthe,' i.e. the hearth of the Low Finery, Be., No. 528.
6 'one anvill to mend the tooles upon', cf. the above-mentioned inventory of the finery at Mitchelpark, of about 1637 — Three of such anvils (3 cws. each) were cast at Kilmackoe furnace, Ireland, in 1624, Cork MS, vol. 14, No. 257 — See Plates xv and xxiv, and also another of Hilleström's paintings, Rönnow, loc. cit., Plate 29, facing p. 128.
7 'half blomes', first mentioned in 1555, Robertsbridge, the total weight being half a cwt., Pe., 381(2) — In 1592, a 'hatchet for cutting of blomes' was made for the forge at Rievaulx, Be., No. 530.
iron from two furnaces. Later the supply (from one furnace) was supplemented by purchases from elsewhere. With a sufficient supply of pig iron even at a small forge such as Bromley, in Staffordshire, the output was high. In 1582, e.g., a total of 131 tons 17½ cwt.s. was produced in 264 working days within the year, which makes a production of almost 3 tons per six-day week. In this figure allowance is made for interruptions caused by repairs of the forge, taking four days, breaking of the hammer and of a hoop on the water wheel, dressing of the bellows, and for not working on all festival and Saints’ days.

The output from Robertsbridge was exceptionally high for a forge in the Weald. That from the other works remained much less. The main reason was that the ore exploited in the Weald was less suitable for the production of wrought-iron bars than for castings. The average output was hardly more than 50 to 60 tons from the late sixteenth to the early nineteenth century in which production in the Weald ceased.

The smaller output of the Wealden forges is significantly shown in the list of English forges operating in 1717. The thirteen forges in the Weald, nine of which were in Sussex, had an average output of 45 tons a year, which is less than half of what the eight forges in Yorkshire produced (average 100 tons). The highest output per single forge was in the Midlands. Of the ten forges with an annual production of 200 tons or more, seven were in Shropshire, Staffordshire (four), Warwickshire and Worcestershire, and of the five with an output of 300 tons or more, one was in Shropshire and two in Worcestershire. The comparative increase in production in the Midlands and the shift towards this area was due to the growing demands of the rapidly developing trade in finished iron products within the area of Birmingham and south Staffordshire.

The yield, or ratio, of pig iron to wrought or bar iron remained unaltered during the whole of the sixteenth century, in which 3 tons of pig iron were required to produce 2 tons of bars. In the following

1 Pe., Nos. 377 and 378 — Straker’s (p. 268) figure of 113 tons per annum is erroneous.
2 PRO, Esch. Various Accounts, Bundle 546, No. 16, vol. 1. The weekly output which had been almost on the same level in 1575-76 (125 tons 4 cwt.s. in 269 working days, Wm. Salt Library, Stafford, D.1734) is high compared with other forges, such as Oakamoors, in Staffordshire (2 tons per week in 1599, Middleton Papers), and Kilmackoe and Lismorin in Ireland (average of 2 tons per week in 1621-22, Cork MS, vol. 11 and 12 passim).
3 E.g., Dunfold forge, Surrey, 55 tons per year from 1580-83, Surrey AC, vol. xvn, p. 273 — The forges at Brightling and Bingleham, Sussex, both supplied by the furnace at Waldron, approximately 60 and 52 tons respectively, from 1639-1715, Straker, pp. 302, 382 — Ashburnham, Sussex, a little less than 50 tons in 1812 and 1814, Accounts at Ashburnham Place.
4 Published Nuv. Tr., vol. ix, pp. 21-22.
5 Sussex (Robertsbridge) 1363, Pe., No. 378(13) — Glamorgan, 1568-69, Pe., No. 387 — Midlands: Cannock Chase (Staffordshire) 1588, BM, Landsdown MS 56, No. 37; forges at Hints and Oakamoor (Staffordshire) 1592 et seq., Middleton Papers; Heanor (Derbyshire) 1591, HMC, Report on the MSS of Lord Middleton, p. 496. London, 1911 — The ratio of 3 to 2 was quite in keeping with the yield in contemporary forges on the Continent, e.g. at Moyeuvre, in Lorraine, in 1565, Beck, SlE., 1905, p. 942 (abstract).
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century, however, the proportion of pig to bar iron improved to 4 to 3, which remained the ratio in the eighteenth century. The yield depended upon the quality of pig iron and coal. If the pig iron was of 'the best sort' and cast of 'the best ore', the yield was better.¹ The quality of the coal also had a distinct influence. At Whitecroft forge, in the Forest of Dean, 27 cwts. of pig iron produced 1 ton of bars, so that the loss amounted to 7 cwts. instead of 6 cwts., as had been expected. The greater loss was due to an inferior quality of the charcoal used in the forge.²

Conversion of pig iron into malleable iron was introduced wherever blast furnaces and their forges were erected. It was practised first in the south-east, and expanded between 1560 and 1570 to the Midlands. Particularly Staffordshire with its many forges became in the seventeenth century a centre whence skilled workers were called to Yorkshire, and later to Lancashire.³

¹ 4 to 3 'generally the quantity allowed', Lewis, vol. iv, p. 168 — For south Yorkshire: Neve. Tr., vol. xix, p. 75 — At Rievaulx it was 3 to 2 from 1577 to 1592, but from 1603 it changed to 4 to 3 and in various years even to 5 to 4, Be., passim — Boate, p. 140.
² PRO, SP, Interregnum, No. 1578, p. 176: 'owing to the badness of the coal used'.
³ In the list of 1717 (see p. 290) seventeen forges are enumerated which was more than in any other county — Skilled workers from Staffordshire were engaged for the forge at Rievaulx: in 1578 a finer, in 1615 a hammerman, in 1636 Blow Harder and his man were sent for 'to worke a trial of Ribulx iron', Be., Nos. 527, 532, 537. For Lancashire see p. 289.
CHAPTER XVII

SECONDARY PROCESSES

The power hammer moved by a water wheel relieved the smith of the most laborious part of his work. The mechanization achieved by its means in the manufacture of iron, however, was limited. It was confined to the production of bars which were only semi-finished products; it did not extend to the final process of fashioning the bars into objects of use. Even for such simple objects as nails manual labour by the smith was required during the whole process from shortening the bars into rods to making the actual nails. Manual labour was indispensable also for intermediate products such as sheets of iron required for the making of hoops, bands, kettles, and pans. Sheet iron and the objects manufactured from it, were frequently produced with hand hammer and anvil at the forge of an ironworks, principally for the ironworkers’ use, but also for delivery to the proprietor of the works.¹

THE FIRST WIRE MILLS IN ENGLAND

Mechanization extending beyond the forging of iron bars commenced in Britain not earlier than in 1566. The turning-point was the erection of the first English wireworks operated with water power. It was built in the years 1566 to 1567 in the immediate vicinity of the ancient Cistercian Abbey at Tintern, in Monmouthshire.² The new enterprise

¹ 'Shithyng' of hoops for the axletrees of the wheels at furnace and forge is frequently referred to in the accounts of Panningridge and Robertsbridge from 1542 onwards, Pe., Nos. 371, 372A, 373, 382(1); in 1552–53 a bar of iron to make a band for a kettle, Pe., No. 380(2). Cooking pans and pails were made at Robertsbridge forge for the manors of Halden and Penhurst, in Kent, in 1572–73, Pe., No. 378. Shovels for use at the ironworks were made at the forge of Rievaulx, Yorkshire, frequently from 1577 to 1615, Be., Nos. 527–529, 531.

² Building started in November 1566, but the 'wire house' was not completed before July 1567. It was 50 feet long and 30 feet wide, and was equipped with four waterwheels, two furnaces for annealing and four hammers for straining the wire rods. PRO, SPD, Elizabeth, vol. 40, No. 65; vol. 41, No. 12; vol. 43, No. 31—The most detailed histories of the works are those by W. Hyde Price in ‘The English Patents of Monopoly,’ Harvard
was started by William Humfrey, Assay master of the Royal Mint in London, and probably a Welshman by origin. Humfrey was the moving power in the early years before the works was taken over in 1568 by a company called 'Society of the Mineral and Battery Works' in London. His position and his keen interest in mineralogy and metallurgy had brought him into contact with leading personalities in public life such as William Cecil Lord Burghley, Chancellor and Secretary of State, and Thomas Gresham, the founder of the Royal Exchange. From the lengthy correspondence Humfrey had with Cecil it clearly emerges that he was the Chancellor's adviser in technical and metallurgical matters.¹

Improvements in methods of wire-production were important in view of the Government's concern to make Britain more self-supporting in respect of manufactured goods. Wire was required for the making of the wool cards indispensable in the wool industry, which in England had been the staple industry ever since the fourteenth century. Since then, wire drawing had greatly improved on the Continent, whilst in England it was still performed by the old traditional method with inferior results. General opinion about this state of affairs is expressed in a memorandum ascribed to 1535–6, in which the need for wire in the realm was stressed. The unknown author, however, added with resignation that wire was one of the products which 'Godd hath ordenyd in other contreys and not in England'.²

Backed by the authority of Cecil, Humfrey had no difficulty in securing the necessary privileges nor in obtaining sufficient support from English capitalists, but it was a harder task to secure the services of a man with the skill and knowledge to erect a wire mill on the Continental pattern. Humfrey was convinced that he had found in Germany the very man he wanted. This was Christopher Schütz, a native of Annaberg in Saxony. He was a disciple of Georgius Agricola.³ In his letters to Cecil, Humfrey could hardly find words appreciative enough to express the high opinion he had of Schütz.⁴ The hopes he reposed in him, however, were not fulfilled. Schütz's family was prominent in the copper industry and trade in Germany. In 1566, however, at which date Schütz came to England, their business was


¹ F. J. Harries, The Welsh Elizabethans, p. 226. Pontypridd, 1924 — For Gresham Humfrey acted as agent in Boulogne in 1564, PRO, Audit Office, Bundle 5, No. 2 — The correspondence with Cecil is preserved in PRO, SPD, Elizabeth, vols. 36, 37, 39–47.
³ Agricola, whose book De re metallica was published in 1556 shortly after his death, was greatly appreciated by his contemporaries such as Erasmus of Rotterdam and Melancthon, R. Hofmann, Dr. Georg Agricola, p. 2, Gotha, 1905. In his letters to Cecil, Humfrey repeatedly referred to him as 'the lanterne of Germany'.
⁴ He called him a man of 'singular knowledge' and 'a jewel as cannot be recovered in lyfe tyme'. PRO, SPD, Elizabeth, vol. 36, Nos. 58, 73, 81 — Tudor Economic Documents, loc. cit., vol. 1, p. 244.

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already on the decline, which may have induced him to find a new sphere of activity in another country.\footnote{1}

The workers Schütz brought over from Germany were all skilled in the production of brass, the main constituents of which are copper and zinc. The production of brass, which was one branch of the new enterprise, was a complete novelty in England. Brass, hitherto imported, was wanted for the manufacture of ordnance as well as household goods. For this reason, the first aim at Tintern was to produce brass. Production of brass, however, was delayed by the difficulty of obtaining the necessary equipment, of which part had to be bought in Normandy. Because of the delay the workers were directed to draw iron wire in the meantime, and this they resented as they had neither skill nor experience in this work. Their unwillingness and lack of skill caused considerable loss in the first year of working. In addition, the wire-making machinery introduced by Schütz required a great deal of adjustment to make it workable. A further obstacle was the inability to produce a suitable iron which could compete with the hitherto imported Osmond iron in respect of ductility combined with tenacity. The situation which had developed was serious enough to threaten the very existence of the newly established wire works, and called for immediate reforms. These were achieved firstly by procuring a foreign worker by the name of Barnes Keysar, a skilled wiredrawer. He caused all the engines used for wiredrawing to be altered, and trained the workers. This took two and a half years because they were ‘so dulle learners’. The second step was to procure an Osmond smith from Westphalia. During all this time wages were being paid, so that considerable loss was incurred.\footnote{2}

Eventually, after all the initial difficulties had been overcome, the production of iron wire became very lucrative. Wire was worked into all sorts of goods, such as wool cards, pack needles, knitting needles, birdcages, mousetraps, rings and rods for curtains, and chains for keys. The principal towns to which wire was sent from Tintern were Bewdley, Bristol, Coventry, Gloucester, Hereford, London, Norwich, and Worcester. The number of workers engaged in the manufacture of wire goods in England was estimated at more than 5,000 in 1597.\footnote{3} To satisfy the increased demand for wire, a second wireworks was erected by the company at a cost of £900. It was built in the years 1607-08 at White-

\footnote{1} Neues Archiv für Sächsische Geschichte und Altertumskunde, Band 57 (1938), pp. 159, 176-177.
\footnote{2} BM, Lansdowne MS No. 76 — £800 were lost because of ‘the naughtie yron, evil drawinge, and marringe and spoilinge both tools and wyer’, ibid. — About the Osmond smith, see below p. 298.
\footnote{3} Statutes, vol. iv, p. 914; BM, Titus B V, fol. 369, Lansdowne MS 52, fol. 59 — PRO, Exchequer Depositions by Commission, 2 Jas. I, Hilary 12. In 1574 a consignment of wire was sent from Tintern to Spain, the profit being 139% clear, BM, Lansdowne MS 24, No. 45. The estimate of 1597 appears to be well substantiated, since it was made by the Company’s solicitor who ‘was sent travelling by the company to find it out’; it is in keeping with various other statements made at the same time (numbers varying from 4,000 to 6,000), ibid., 39 Eliz., Hilary 23.
XXV  Staff with ball of Osmond iron coiled round the end. Museum of the Castle of Altena in German Westphalia. By courtesy of the Verein Deutscher Eisenhüttenleute, Düsseldorf.
XXVI Plating mill with three small hammers moved by one wheel. On the left in front an anvil is shown on which a shovel is made. From a painting by the Dutch artist Jan Breughel (1568-1625), Venus at the Forge of Vulcan. Staatliches Museum, Berlin.
brook, in Monmouthshire, which, like Tintern, was near to the western banks of the river Wye, but farther up the Wye valley.\(^1\)

By the privileges granted, a complete monopoly was ensured which was jealously guarded against any infringement. The first violation was made by a member of the company, Sir John Zouch, owner of several ironworks in Derbyshire. In 1581 he erected a wire mill at Mackenay, Derbyshire, but the company successfully insisted that work should be stopped. Sir John, however, was persistent, and two years later the mill was reopened, but the company again enforced its immediate suppression and to make sure that work had ceased, an expert from Coventry was sent to Mackenay under the pretext of buying wire.\(^2\) A much more dangerous infringement was made about 1602, at which date an iron-wire mill was erected at Chilworth in Surrey, not far distant from London. Thomas Steere who established it proceeded very thoroughly. By enticing skilled workers from Tintern he was able to copy their methods of wire-drawing to the smallest details. After legal proceedings against Steere the competitive enterprise was suppressed in 1606. Steere, however, had proved to be so ingenious that the company gave him employment in their own works at Tintern.\(^3\)

**THE PROCESS OF WIRE-DRAWING**

The method used at Tintern was first described by John Ray in 1675. Despite the late date, his description is quite consistent with documentary evidence of the sixteenth century, in which are laid down the various functions performed by the wire workers during the process, and the products obtained at each stage. The method remained essentially the same from its early beginnings until the eighteenth century.\(^4\) Wire-drawing proceeded in three consecutive stages:

(1) Firstly, small iron bars, square in section, from the forge were heated in a furnace and then strained, i.e., elongated into rods of 'about the bigness of one's little finger, or less' by the action of a hammer moved by water power. Such hammers, termed 'straining

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\(^1\) *Court Books of the Society of the Mineral and Battery Works*, deposited at the BM, vol. iii, fol. 45v and 152 (referring to a lease of land granted 16th June 1607 for 90 years). Of the Court Books, in which the decisions made at the sessions of the Society in London are recorded, only vols. i (1565–86) and iii (1621–1713) are preserved.

\(^2\) In addition to various entries in the *Court Books*, see PRO, *Escheater Special Commissions*, No. 611.


hammers’, were introduced by Schütz— the four he erected were operated later by himself and for his own profit under a lease obtained in 1573. Shortly after his death two more hammers were built by Richard Martin in 1581. The straining hammer was evidently introduced from Germany, the corresponding German term being ‘Reckhammer’. It was a tail-hammer, much lighter than the usual power hammer of the forge and accordingly striking much faster. Generally it was used for working iron bars into rods and bands. The elongated bars were heated in a furnace and then annealed, which took about twelve hours, after which they were laid in water where they remained for from one to two months.

(2) The second stage was carried on mainly by the rippers. ‘Ripping’ was cutting the rods into smaller sizes, and rounding them with hand hammers, after which they were drawn through a draw-plate with two or three tapering holes in it. The side of the draw-plate at which the rods were inserted was of iron, the opposite side, which required greater resistibility, was of steel.

For forcing the rods through the draw-plate the rippers used a peculiar device which is described by John Ray in detail. It was an engine shaped like a small barrel and furnished with hooks to which pincers were attached. When the ripper had fastened the pincers to the end of the wire which appeared in the hole of the draw-plate, the wheel removed barrel and hooks from the plate, thus drawing the rod through the plate. When this operation was finished the barrel fell by its own weight back towards the plate. The new device constituted an important step towards mechanization: for the work formerly effected by the power of the girdleman’s body with the help of a girdle and a swing, mechanical power was substituted, leaving the ripper with no more to do than fasten the pincers to the wire-rods.

The operation was followed by a second annealing which lasted at least six hours, and a second watering which took about one week. After this, the operation of drawing with the barrel was repeated. The wire then acquired the size of a ‘great Pack-thread’. When the rippers had finished with their work completely, there was a third annealing and watering lasting one week. The repeated annealing was done so that the wire, which had been hardened and rendered brittle by the action of drawing, should be softened again for further drawing. The

2 Court Books, vol. 1, fols. 100v, 101, 101v, 124v — BM, Lansdowne MS 36, No. 47.
3 Illustration of a German Reckhammer (from a drawing of 1698), Joh., p. 234, Bild 183. See also the illustration of a similar tail-hammer used at the Osmund forge, below p. 301, fig. 94.
4 Wages paid to the rippers for ‘rippinge and roundinge’ (ab. 1583–90), BM, Titus B V. fol. 369. In the eighteenth century, however, ‘rounding’ was effected by the draw-plate, the wire beginning to be round after the fourth or fifth hole, Lewis, vol. iv, p. 187 (from Cockshutt, Wortley).
maximum temperature to be generated in the furnace was ‘a good red’ heat (ab. 900° C) according to Cockshutt. When that was reached the wire was withdrawn very slowly, so that it cooled gradually.

(3) At the third stage of the process no further annealing or watering was required. The wire was delivered to the small-wire drawers for further reduction to extreme slenderness. Wire drawn so fine had never been produced in England before the installation of the wire mill at Tintern, an enterprise repeatedly extolled by contemporaries in glowing terms. This fine wire was of five sorts varying in size and price: clavant, bastard, fine, fine fine, and northern wire, selling in 1594 at prices from 4s. 4d. to 7s. per stone (of 14 lb.). ‘Northern wire’ was probably sent to the northern counties to be used for the manufacture of wool-cards required for the woollen industry. The demands of this extensive industry were great, and this may have been the reason why Sir John Zouch was so anxious to set up a wire works in Derbyshire.

According to Ray the small-wire drawers were also called ‘overhouse-men’, because they worked in an upper room. The engines they used were moved by three axles driven by the same water wheel. Unfortunately, Ray gives no detailed description. There is, however, no doubt that rotating drums or blocks were used, around which the wire coiled. At Tintern they are referred to as ‘rollers’ in 1568 and 1569, and in 1747 the term ‘blockmen’ was applied to the fine-wire drawers. These drums, or ‘pulleys’, were recommended by the Italian Vannoccio Biringuccio for the drawing of iron wire very fine. They were mounted on vertical axes upon a draw-bench with a draw-plate in between them.

The operation of wire drawing, in particular at the final stage, was facilitated by lubrication. Train-oil and tallow were among the requisites in 1588 at Tintern. Tallow was mixed with the train-oil to stiffen it at the last stage, when the wire became very thin.

ENGLISH OSMOND IRON

The prosperity of the wireworks depended essentially upon the quality of the iron used as raw material. It was the tenacity and ductility of the special Osmond iron which made it possible to draw the wire finer and smaller than ever before, and started a new era in the English wire industry.

The difficulties which had to be overcome before Osmond iron was produced are described by John de la Haye in his treatise on metalurgy. He states that the iron had to be heated to a bright red heat and quenched in water. This process was repeated several times until the iron was sufficiently hard and strong. The wire was then drawn through a series of dies until it reached the desired thickness.


2 Illustration V. Biringuccio, Pirotechnia, fol. 140v. Venetia, 1540; reproduced by Jah., p. 175, Bild 132.

produced were not small. The great losses incurred in the early years made the company very reluctant to invest in new devices, the urgent necessity of which was not understood by the majority of the members. It was due to Humphrey's unceasing efforts that the process of producing Osmonde iron was ultimately established. His first step was to procure an expert maker of Osmonde iron, namely one Corslett Tinkhaus, a native of the south-western part of Westphalia, where the manufacture of wire and of the Osmonde iron required for it had attained a high standard. He introduced all the equipment necessary for the making of this iron which proved to be more 'apt for the making of wyre than any iron before that time wrought' in England. Tinkhaus arrived in Wales in 1567 and worked first at Rhyd-y-Gwern, a hamlet in the Glamorganshire part of the parish of Machen. Shortly after his arrival Humphrey sent him to Sussex to make a trial with Sussex iron at the forge of Bryan Hogge. The Sussex iron was obtained from the forge at Robertbridge, but it is not known exactly where Bryan Hogge's forge was. A forge for the making of Osmonde iron situated within easy reach of Tintern was not erected before 1568, at the end of which year it was ready for use. Judging by the distance from Tintern the locality was Monkswood. Up to then, ordinary bar iron had been used in this neighbourhood for the drawing of wire, with the result that the wire was rejected by purchasers, and large quantities of it remained unsold at Tintern. As soon as Osmonde iron began to be used for wire drawing, the situation was transformed. The new wire proved to be so good that purchasers at Bristol and Gloucester ordered 'so much as shall serve their whole trade with'. Production of Osmonde iron did not remain confined to Rhyd-y-Gwern and Monkswood. It was also produced in the last quarter of the sixteenth century at the forges of Pontymoel and

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1 For the following see Humphrey's letter of the 24th August 1577 to Cecil, BM, Lansdowne MS 24, No. 25 — PRO, Exchequer Deposition by Commission, 2 Jas. I, Hilary No. 12 — Stringer, loc. cit., p. 201 ('Corsett a German born who at his coming over into this realm first devised more commodius engines than ever before was known or used in England') and p. 209 ('engines, tools and devices as were first used and invented by the said Corset, for the making and housing of Osmonde Iron') — Evidence of the origin of Corset Tinkhaus kindly supplied by the Archive at the Castle of Altena, in Westphalia.

2 In July 1569 two members of the Company ordered to investigate the state of the wireworks and of the attached ironworks, were sent to Machen ('Maugham') as well as to Tintern, BM Court Books, vol. 1, fol. 92, Lansdowne MS 76 No. 72. 'Mawghin' was one of the Company's ironworks demised in 1570, BM, Add. MS 12503, fol. 156. The only place in the parish of Machen at which the manufacture of Osmonde iron was carried on in the seventeenth and eighteenth centuries was Rhyd-y-Gwern, NLW., Tredegar Collection, Box 7, Machen; Cardiff Public Library MS 444-49. This was the forge which was seized in a law-suit against Edmund Wheeler in 1597, APC, new series, vol. xxix, pp. 23-24. Corslet Tinkhaus' descendants took 'Corset', which had probably been a nickname, as their family name and remained Osmonde makers in Monmouthshire and in the parish of Machen until well into the eighteenth century — J. Davies, 'The Industrial History of the Rhymney Valley', p. 54, Thesis, University of Aberystwyth, 1936.

3 Pe., No. 154. Probably the forge was at Maresfield, as Bryan H. lived there in 1566 (Parish Registers).

4 PRO, SP Dom., Elizabeth, vol. 47, No. 11; vol. 48, No. 43.
Secondary Processes

Pontypool in Monmouthshire. The 'Osborn Forge' at Pontypool was still in existence in the early nineteenth century.

Carefully selected ores were required for Osmond iron. The most suitable was discovered about 1577 in a mountain called Elgam near the river Avon, in the Lordship of Avergavenny in Monmouthshire. It was regarded as 'the best ore for Osmond iron'. Apparently, it was mined near Cwm Avon. The ore contained a fair amount of protoxide of manganese (1.03%) and not more than a trace of sulphuric acid.

The improved quality of the iron obtained from ores selected with a view to producing Osmond iron induced Richard Hanbury after he had acquired the ironworks of the Company of the Mineral and Battery Works to deliver only iron of lower quality to Tintern for wire drawing, while he sold the best iron to various other purchasers, in particular to smiths for the making of scythes and tools. As a result the wire workers of Bristol and London complained about the Tintern wire, which compelled the Company to sue Hanbury. In the course of this law-suit trials of iron in respect of its fitness for conversion into Osmond iron were made at Pontypool in April 1596 and shortly afterwards at the forge of Lydbrook on the northern fringe of the Forest of Dean. The iron tested was pig iron from Pontypool, from the Forest of Dean, and from Sussex.

Production of Osmond iron continued in the Forest of Dean in the seventeenth century. It was delivered to the lessees of the wireworks at Tintern and Whitebrook. From 1646 onwards and in the early eighteenth century the wireworks were in the hand of the Foley's. During this period the Osmond iron required for wire drawing was produced at the Upper Forge at Lydbrook in the Forest of Dean, the Upper Forge at Tintern, and at Machen in Glamorganshire.

The Process of Making Osmond Iron

The process employed had some resemblance to the process of refining conducted in the ordinary forge, but there were differences. Although

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1 PRO, Exchequer Special Commissions, No. 1518.
2 D. Walkinshaw, Local Register, or, Chronology of Pontypool, 4th edition, p. 4. Pontypool, 1875.
3 PRO, Exchequer Bills and Answers, vol. 29, No. 12; Depositions by Commission, 39 Eliz., Hilary No. 23—'Analysis', Percy, p. 220, No. 70 (cf. p. 234) — Attempts to exploit ores mined at Abercarn failed. Although the percentage of manganese was higher (1.50%), the high percentage of sulphuric acid (1.30%) made it unsuitable, PRO, Exchequer Special Commissions, No. 1518; 'Analysis', Percy, pp. 220 (No. 74) and 233.
4 PRO, Exchequer Rolls and Answers, Bundle 29, No. 32; Depositions by Commission, 39 Eliz., Hilary No. 23.
5 George Myrne had a lease of the wireworks at Tintern from 1627—39, and also of those of Whitebrook from 1699—45 jointly with Sir Basil Brooke. NIL, Badminton, No. 2245, p. 45; Court Books, vol. i, fol. 23 and 86; PRO, Exchequer Bills and Answers, Bundle 182, No. 169.
no direct description of the English Osmond forge and the process involved exists, a reconstruction is rendered possible by the fact that the manufacture of Osmond iron was introduced from the County of Mark in the south-west of German Westphalia. That the process was, and remained, the same as in the country of its origin is witnessed by the German mining engineer Eversmann who was sent by the Prussian Government to England in 1784 to study progress in the English iron industry and the possibility of introducing new English devices into Prussia. On his journey he visited Pontypool where he studied the method of making Osmond iron. He was so much struck by the conspicuous similarity of the processes conducted at Pontypool and in the Westphalian Mark, that he arrived at the conclusion that the former must have been introduced from the Mark. For this reason Eversmann's description of the Westphalian process is a perfect substitute for a description of the English process.

The hearth or fireplace in which the process was carried out was narrower than that of an ordinary English finery. Between the tuyere and the opposite side the width was one instead of one and a half feet. The length from the front to the back plate was the same as in the ordinary finery, but only on the top, because at the bottom the front part consisted merely of coaldust. On the other hand, the fireplace was very much deeper, i.e. 13-14 inches instead of 9. The tuyere was about 7 inches distant from the back plate. The tuyere projected 2 inches into the fireplace. It was steeply inclined, so that the blast covered two-thirds of the bottom.

When the fireplace was filled with charcoal, and the fire lit, a very strong blast was turned on. It was produced by a pair of bellows the dimensions of which were only slightly smaller than those at the finery (6 instead of 6 1/2 feet long). A pig about 3-3 1/2 feet long was pushed into the hearth through an aperture in the back wall exactly as in the finery, and placed slightly diagonally towards the tuyere. As the fireplace was of a greater depth, the end of the pig protruding into it came 4 or 5 inches above the tuyere. The iron melted down from the pig in liquefied drops which passed through the blast and congealed at the bottom into small lumps. These semi-refined lumps were raised with a small bar from the coals into the fire and exposed to the oxidising blast. When they

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3 The process which is essentially one of refining had nothing in common with the process conducted in the Swedish Osmond furnaces (described by Percy, pp. 320-326), which was a process of producing malleable iron directly from bog or lake iron ore with wood as fuel.
4 See above p. 287, note 4.
melted down they were intercepted and collected drop by drop at the end of a large staff held in the fire, or, if necessary, pressed against the staff with the small bar. During the process of collecting the melting particles of iron, the staff was turned round quickly, so that the particles were coiled or twisted round the end of the staff, until a regular mass or ball was formed (see Pl. XXV).

Collecting the particles of iron and coiling them round a staff was the part of the process of making Osmond iron which chiefly distinguished it from ordinary refining. As the semi-refined iron exposed to the blast while the staff was turned was in very thin layers, the oxidising blast could work on it more easily and thoroughly. The effect, apart from decarburisation, was a more complete purification, which was promoted by periodically dipping the ball forming at the end of the staff into a bath of rich slag which was constantly kept in the fireplace.

When the ball had attained a weight of about 25 lb., staff and ball were taken immediately to the hammer. While still very warm they were worked first gently to remove the surface slag, and then with strong quick strokes. The implement used was a small tail-hammer.

The cast-iron hammer head (A) was considerably lighter than that of the usual forge hammer (3 cwt. instead of 5 cwt. or more). The helve of the shaft (B) which passed through the uprights (E), instead of being lifted at its ‘belly’, i.e. between the uprights and the hammer head, was lifted at the tail end (C) by knobs fixed on a cast-iron frame (D), moved by the rotating axletree of a water wheel. The lightness of the hammer head enabled it to be moved with considerable velocity, so that forging took less time and the iron remained hot during the procedure, without the necessity of being re-heated in a chafery. Moreover, by the lighter and quicker strokes of the smaller hammer a better consolidation of the iron was achieved than by the slow and heavy strokes of the ponderous forge hammer.

The loss of iron burnt away amounted to $25\frac{3}{4}\%$ as a maximum, but mostly it was somewhat less. The consumption rate of charcoal was higher than in the ordinary power forge, and only best-quality charcoal was used.\(^1\) The great speed required for working combined with the

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\(^1\)At Lydbrook Upper Forge, in the Forest of Dean, 2 loads 11 sacks were required for the making of Osmond iron against 2 loads 7 sacks for ordinary bar iron, in 1710–11.
tremendous heat generated by a vehement blast in a very small fireplace laid an unusually great strain on the worker, which necessitated a reduction of working hours. All these factors, to which must be added the requirement of selected ores, made the manufacture of Osmond iron more difficult and more expensive than that of wrought-iron bars produced by refining and hammering in the power forge.

**IRON BATTERY**

In the first half of the sixteenth century the process of flattening bars of iron into plates and sheets was still conducted in Britain exclusively by hand, apart from one exception. An armouy 'mill' was set up by Henry VIII in 1511 at the west side of the palace at Greenwich for the special purpose of introducing the foreign art of chasing and inlaying decorative armour, the armourers employed being Germans, Flemings, and Italians from Milan. This armouy, however, was an isolated establishment operated for the benefit of the Crown only. It was not before the erection of the wireworks at Tintern that the method of flattening iron by means of a water hammer into plates and sheets was made available to English ironmasters. Although the process, which was termed 'battery', constituted a great improvement, the new method found its way into the British iron industry only very gradually. It was a part of the privileges granted to Humfrey and Schütz in 1565, and later to the company of the Mineral and Battery Works as their successors. The first evidence of the practical use of the new method, however, is of a much later date. A mill for making armour plates was built by the company on the river Cray at Crayford near Dartford in Kent. It is first referred to by the Privy Council in 1595 with the remark that the plates made for armour were 'verie good and serviceable'.

Johnson, 'New Lights', loc. cit., p. 131 — At Pontypool, about 1750, three dozen of charcoal 'of the best' were required, NLW, Tredegar Collections.

1 'Shithynge' of hoops for the axletrees of the wheels at furnace and forge is frequently referred to in the accounts of Panningsbridge and Robertsbridge from 1542 onwards, Pe., Nos. 371, 372A, 373, 382(2); in 1552-3 a bar of iron to make a band for a kettle, Pe., No. 380(2). Cooking pans and pails were made at Robertsbridge forge for the manors of Halden and Penhurst, in Kent, in 1572-3, Pe., No. 378. Shovels for use at the ironworks were made at the forge of Rievaulx, Yorkshire, frequently from 1577 to 1615, Be., Nos. 527-9, 531.


3 17th September 1565, 'plate as well convenient and necessary for the making of Armour as also for diverse other nefefull and profitable uses', PRO, *Chambers Warrants*, No. 1152.

The device adopted for the process was evidently the German battery mill, as one of the improvements expected to be introduced by Christopher Schütz was mills 'for the plating of iron and steel for armour', Humfrey to Cecil, 16th August 1565, printed *Tudor Economic Documents*, vol. 1, pp. 243-245, London, 1924.

Secondary Processes

Battery, or plating, mills were small establishments, which often had only one water wheel. Hammer and anvil were similar to the small hammers and anvils used at the Osmond forge, and to the straining hammers introduced from Germany by Christopher Schütz for elongating iron rods preparatory to wire drawing. At the battery mill, however, hammers and anvils had broader faces (see Pl. XXVI).

A typical example of such a mill in England is a 'battering woorke' erected by Thos. Smarte, a blacksmith of Ruerdean, in Gloucestershire, in 1622 at Lydbrook in the Forest of Dean. It had a pond fed with water drawn through a channel out of the mill stream of a disused corn mill. In the licence granted in 1621 by the Mineral and Battery Works by virtue of their monopoly, the stipulation was made that not more hammers should be set up than one water wheel could drive. At the mill strakes for wheels, ploughshares, and plates for pans and for armour were produced. After the licence had expired in 1628, the lease of the mill seems to have passed to Sir Basil Brooke who apparently still operated it in 1635.1

Plating mills were erected in other counties also. In 1605 the company granted a 'lease of the iron-batterie' in the county of Somerset to one Thorpe. Where the mill was erected is not known, but there is evidence that it was still working in 1621.2 Another plating mill, the property of the Earl of Southampton, is referred to in 1623.3 Such mills, however, appeared to have been still rare in the seventeenth century. In Ireland there was none in 1665, at which date an application was made for a licence to set up a 'plat mill for iron batterie, to make frying pans, dripping pans, salt pans, fire shovels, armour for back, breast, and head, and all sorts of iron plates'.4

Frying pans were made from flat plates produced at the plating mill and cut into circular shape. The round plates were hammered, first singly and then two, three, or four together. The heat applied was not allowed to be so strong as to make the plates stick together. The method of hammering the hot plates jointly had the advantage of a better heat preservation. It also prevented scaling. When this flat work had been

it was the battery mill erected 'neere Erith' in the reign of Queen Elizabeth I, which is referred to in a letter written by John Martin in 1624. M. pointed out that the 'platers' who had come from abroad were all dead except one who was 'so cunninge and obstinate' that he would not teach any Englishman the 'true misterie of plating', Ch. Floulkes, The Armourer and his Craft, p. 188. London, 1912.

1 Lewes, Sussex Archaeological Trust, Gloucestershire Charters belonging to Viscount Gage, GG 676. BM, Court Books of the Mineral and Battery Works, vol. iii, fols. 6, 26, 29v, 32, 72.
2 Court Books, vol. iii, fols. 2, 2v, 3v.

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completed, the plates were given the required shape. To achieve this, the plates, usually nine, were laid one upon the other and clamped firmly together, whereby again heat was preserved and scaling avoided. The great art in this process was to apply the right heat and to use the right weight of hammer; altogether twenty different hammers were used. The manipulation required so much skill that in the 1680's not more than two forge-masters in England were able to make frying pans by the method described. One was John Holland who worked two forges in Staffordshire, at Newcastle-under-Lyme, and in the parish of Keele. The other worked at Wandsworth in Surrey. Both also made dripping pans, the manufacture of which was less difficult, as they were only forged singly.¹

Iron plates were produced by the use of battery hammers quite late and in a period in which the rolling mill already had been adopted.² This was because battery hammers were still essential to produce certain results. Better shovels, for example, were made by hammering. The plating hammer gradually reduced the thickness from the straight to the cutting edge, while rolled shovels could only be of uniform thickness throughout. The difference between a rolled and a hammered tool was of particular importance where a cutting edge was needed.

THE ROLLING AND SLITTING MILL

Despite the obvious advantages of the water hammer, there were limits to what it could do. It could not draw bars to less than ¾ inches square, because they were too flexible when hot and cooled quickly. For this reason, if small bars were required, it was necessary to have recourse to a slitting mill.³

The origin of the slitting mill is obscure. Mills for the slitting of iron were known shortly after 1500, or perhaps a little earlier, in the district of Liège in Belgium, and in Germany also.⁴ In England, evidence of a slitting mill comes from a much later date. The first licence to set up such a mill was granted to Bevis Bulmer, the great Elizabethan mechanic and mining engineer. On the 4th December 1588, he obtained a patent which gave him the exclusive right for twelve years to erect and to operate in England and Wales a new "engine or instrument" worked by water power. The object of the engine was the cutting of

¹ Plot, pp. 335-336.
² In an inventory of the stock remaining in 1724 at Cradley furnace, in Worcestershire, "5 plating hammers" and "6 plating anvils" are referred to which bears out that they still were in use in the district at such a date, Dudley Library — An "iron-plating forge" was at Samquhar, parish of Kirkcowan, county Dumfries, in Scotland, in the 1790's. J. Sinclair, *Statistical Account of Scotland*, vol. v, p. 450. Edinburgh, 1794.
⁴ ibid., pp. 110, 167.
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iron into 'small barres or roddes', principally for nailors, which would
save the laborious and tedious work of cutting by hand with chisel and
hammer.\footnote{PRO, Chancery Patents Rolls, No. 1333, memorandum 27-28. Abstract: E. Wyndham Hulme, 'The Early History of the English Patent System', p. 135, Tracts in English Law. Boston, 1909. An earlier patent granted to Peter Anthony van Ghemen in 1567 for 21 years (ibid., p. 127) was only concerned with 'mollyfying', i.e. softening, and tempering the iron, so as to ease the subsequent work of cutting and to save fuel. Full text in BM, Lansdowne MS 101, fol. 82.}

It is not known whether Bulmer put his device into practice. In
1590, however, a slitting mill is supposed to have been erected on
the river Darent at Dartford, in Kent, by Godfrey Box, a native of
Liège in Belgium. There is no contemporary evidence; the only fact
known about Box is that he died in 1604 at Dartford leaving two
daughters.\footnote{VCH, Kent, vol. iii, p. 988.}

Bulmer's patent, which gave him a complete monopoly for England
and Wales, expired in 1600, and there is no evidence that any new
patent was issued before the end of 1618, when one was granted to
Clement Daubeney, or, Dawbeney.\footnote{11th December 1618, 'engines to be driven by water for cutting of iron into small bars', for 21 years, Cal. of SPD, James I, 1611-16, p. 602. London, 1858. For the following see also J. Nicholl, Some Account of the Worshipful Company of Ironmongers, vol. i, pp. 164-168. London, 1866.} In 1613, when he had applied for
a patent, a storm of indignation arose among the nailors, blacksmiths,
and ironmongers of the City of London, because they feared the
patent would put a stop to the importing of iron rods, on which their
living mainly depended. Despite their remonstrations, a slitting mill
was erected by Daubeney, and it greatly benefited the nail trade, as
emerges from statements made by Sir Francis Bacon the philosopher
and statesman who as Solicitor-General made the final recommenda-
tion in favour of Daubeney's petition.\footnote{PRO, SPD, James I, 1611-16, p. 430; APC, 1615-16, p. 490-491; Cal. of State Papers relating to Ireland, vol. 235, No. 49a, ibid., Addenda 1625-60, p. 265.} The site of the mill, how-
ever, is not known; it may have been somewhere in the vicinity of
London.

From the controversies of 1613 emerges another fact; a slitting mill
had already been erected by William Burrell of Deptford in Kent, who
was a master carpenter to the East India Company of London. The
mill was built on the company's Irish plantation in County Cork at
a place near the Castle of Dondanier (now Dondaniel) where the com-
pany had a plant for shipbuilding and an ironworks.\footnote{Cork MS, vol. 3, No. 111; Cal. of SPD, James I, 1611-16, p. 490; APC, 1615-16, p. 490-491; Cal. of State Papers relating to Ireland, vol. 235, No. 49a, ibid., Addenda 1625-60, p. 265.} A further slitting mill in Ireland was erected in 1624 on the river Bride at Tallowbridge,
County Waterford. It was built by Richard Blacknall and Henry
Wright, the tenants of Richard Boyle's ironworks. The mill was attached
to a 'nailhouse' which was equipped with 'VIII fordges and harthes'
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for the making of nails, edge tools, and battery ware. In 1626 Boyle sent to England for a 'skillful workman' able to take charge of the slitting mill.¹

The two main channels through which iron rods came to the English market are referred to in the above-mentioned controversies of 1613. Iron rods at this time were for the most part either imported from Flanders or produced in various English counties whereby 'thousands of poore men' made their living. Iron rods from Flanders were considered superior, since they were of 'tough iron'. Home-produced rods were made of cold short iron, which was of much inferior quality but sufficed for the making of small nails. Nail-making had steadily increased in the Midlands in the course of the sixteenth century, and in the seventeenth the centre of production shifted from the Birmingham area to the district of Dudley and Stourbridge.² Considering this development, it is not surprising that the slitting mill appeared in the Midlands also at an early date. The first evidence is from 1622–23, referring to a slitting mill in connection with a forge at Bromley in Staffordshire on the estate of Lord William Paget.³

The early installation of slitting mills in Ireland and in the Midlands appears to contradict a belief frequently found in history books according to which it was Richard Foley who introduced the slitting mill, if not in England, at least in the Midlands. Foley, a Stourbridge ironmaster, set up a slitting mill at Hydehouse on the Stour, in the parish of Kinver in Worcestershire, at a cost of £500, in about 1625.⁴ This is the historical fact which has given rise to a romantic story according to which Foley disguised as a beggar went to Sweden and studied the mechanism of the Swedish slitting mill and the operations involved. He is supposed to have introduced both in England after his return.⁵ It is extremely improbable that Foley should have obtained the pattern for his mill from Sweden, as in that country the slitting mill was not introduced earlier than 1626 (from Liège) and perhaps even a few years later.⁶ This would have left Foley hardly any time to go to Sweden. The story, however, should not be dismissed as completely without foundation, for it does contain a nucleus of historical fact.

³ General Receiver's Account, Wm. Salt Library, Stafford, D1734.
⁴ PRO, Chancery Decrees and Orders, vol. 157, pp. 265–266, Chancery Proceedings, Chas. I., W 47, No. 63. The date is not absolutely certain; in May 1633 it had been erected 'about 8 years since', which would be 1625. In any case it was in full operation by 1629.
⁵ The story is related by H. Scrivenor in the first edition of his History of the Iron Trade of 1841, but omitted in the second edition of 1852. It is reprinted by Percy, p. 731. A very similar story is told about John Cockshutt who was credited with the introduction of wire drawing from Germany, P. Longmuir and J. Kenworth, 'Notes on Early Wire-drawing Practice', Engineering, 1913, p. 542.
⁶ Yearneaux, pp. 298–299.
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Although the slitting mill that Foley erected was not the first in Britain, nor even in the Midlands, it does appear to have been of a new type which from that time forward remained the prevailing type in Britain until near the end of the eighteenth century.

To judge of the advantages possessed by this new type, it is necessary to consider first the nature of the machines used in the earlier slitting mills. Rhys Jenkins suggested the use of oscillating shear blades, probably cutting two or three rods at a time and worked by a water wheel. Mechanical cutting of metal plates with shear blades was known in England at the time of Bulmer's patent. At the copper works at Keswick, in Cumberland, the equipment brought over from Germany between 1565 and 1569 included large shears of iron set in a framework of wood. Rolling the bars into plates preliminary to cutting may also have been done in the earlier slitting mills, since the use of plain rollers was known in the English iron industry in Bulmer's time. They are mentioned in an inventory of 1609 relating to the disused steelworks at Robertsbridge in Sussex, which had been erected in 1565, and operated by German steelmakers. The rollers, however, were apparently not moved by water power, but by hand. It also has to be taken into consideration that rolls with circular cutters for slitting which later constituted the most essential device of the slitting mill were still rare and difficult to obtain even in Germany as late as 1605, although they had been in use there at some places much earlier. All this justifies the conclusion that Bulmer's slitting mill and the few others built in Britain before Foley's day, had iron rollers for rolling the bars into plates and large iron shears for mechanical cutting. The whole establishment must have been comparatively small as is evident from the records of the cost of construction. At Tallowbridge in Ireland in 1624 this came to only £150 which also paid for the erection of the adjoining nailhouse. When a new slitting mill was built not far from the above, at Boyle's forge at Lisfinny near Tallowbridge in 1633, the cost was more than three times as high, which indicates that the new

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2 'Il payer of large and stronge greate iron shears to cutt copper withe, the same beinge set in sundry postes and bounde with iron', Inventory of 1588, BM, Sloane MS 2487, fol. 2.
3 Referring to rooms for the 'placing of Roles for the Steele worke', BM, Add. MS 5680, fol. 61. There is no evidence of water power. The first picture of a rolling mill (with water power) is supplied by Vittorio Zonca, *Novo teatro di machine e edifici*, p. 82, Padova, 1607, reproduced by W. B. Parsons, *Engineers and Engineering in the Renaissance*, fig. 65, p. 139. Baltimore, 1939.
4 At a combined rolling and slitting mill at Aslar, near Wetzlar, erected in 1606–07 the plain rollers employed were cast at the local furnace. The cutting rolls necessary for slitting, however, could not be obtained from anywhere in the vicinity, although quite a number of ironworks were operated in the valley of the Lahn and in the adjoining districts of Nassau. They had to be procured from the distant territory of the Saar at considerable expense for transport. Fünftliches Archiv at Braunsfel, Hauptarchiv 1, 6 II and Rechnungsarchiv III 3. See also H. Schubert, *Das Eisenhüttenwesen im Gebiet der mittleren Lahn und des Vogelsberges, Boden- u. Eiseurmwerke Wetzlar*, vol. 1, pp. 79–80. München, 1938.
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mill was very much larger. The cost of building this latter mill was exactly the same as those incurred by Foley for the slitting mill at Hydehouse in Kinver. So it may safely be assumed that both mills represented a new and larger type of slitting mill and that this type was introduced first by Foley, although it is not possible to ascertain what was his model.

The construction of this new type of slitting mill, and the manner in which it was operated can be derived first from details preserved in documents of 1633 and 1634 relating to the mill at Lisfinny. It was worked by water conducted in a watercourse from a pond, and had only one furnace. Since it is stated that sixteen pieces were heated at a time they must have been small, which suggests that they were from bars clipped into short lengths. The heated pieces were first 'drawen out' which indicates the use of plain rollers, and this conclusion is supported by evidence from 1629, when Thomas Ledsham, who was later entrusted with the operation of the mill, proposed to Boyle to convert a hundred tons of iron into 'sheet'. The remainder of the work was left to the slitters, and the finished rods were bundled up ready for sale.

As far as can be deduced from the available details the Irish slitting mill erected in 1633, and accordingly Foley's slitting mill built at Hydehouse in Worcestershire between 1625 and 1629, represent a type which conforms with the English mill described by Plot in 1686. Plot's description, however, is somewhat more detailed than the documentary sources, and he says that the heat generated in the furnace was a red heat (about 850° C), and that the pieces were taken singly from the furnace to the rollers to be 'drawen even and to a greater length'. Then they were immediately passed, still hot, through the cutters 'which are of divers sizes, and may be put on and off'. Plot's description is not accompanied by a drawing. The first drawing to illustrate the mechanism and operation of an English slitting mill, is of 1758. There follows a detailed description of the process involved, which tallies with Plot's.

Description

1 AB the slitting mill, CD the plate (i.e. rolling) mill, SP the clipping mill. EF are two great water wheels. After the water has passed the

1 Ibid., p. 120 and vol. iv, p. 17. Cork MS, vol. 17, No. 163. Chatsworth MS 78, p. 754. The expenses were estimated at £400, but finally amounted to £500.

Like the earlier slitting mill, the new one also appears to have been introduced from England. Thos. Ledsham who worked it, previously had lived in London (in 1629), Grosart, first series, vol. ii, p. 305.

2 Cork MS, vol. 17, Nos. 163 and 185. Grosart, first series, vol. ii, p. 305. The sale of slit iron did not turn out as well as expected. In 1638 and 1639 attempts were made to sell in the Low Countries, but Boyle's slit iron was not wanted there because of its inferior quality. In 1640, 67 tons stored at Youghall were rejected, since, as Boyle's clerk reported, 'it is so bad, being rough and ill drawen'. Cork MSS, vol. 19, Nos. 69 and 129; vol. 20, No. 68; vol. 21, No. 20.

3 Plot, p. 163 — The equipment of the rod or slitting mill at Cradley, Worcestershire, of 1724 conforms to Plot's description, Inventory of Cradley, Dudley Public Library.
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wheel E moving in direction of QW, it comes about to the wheel F, in direction of YX. The water wheel E with the lantern G on the same axis, carries the spur wheels M and H, with the cylinders B and D. And the wheel F with the lantern I, carries the wheels N and K, with the cylinders A and C. The cylinders A and B, as also C and D, run contrary ways about. And the cylinders A and B are cut into teeth, for slitting iron bars. C,D are 8 inches diameter; A and B about 12 inches. And these cylinders may be taken out and others put in, and may be brought nearer to, or further from, one another, by help of screws,

![Fig. 35. Slitting mill.](image)

which screw up the sockets where the axles run. The axles of N,I,K lie all-in one horizontal plane. And so does M,G,H. But the cylinders A,B, and also C,D, lie one above another.

For making plates, if a bar of iron be heated and made thin at the end, and then that end put in between the cylinders C,D, whilst the mill is going, the motion of the cylinders draws it through, on the other side, into a thin plate. Likewise a bar of iron being heated and thinned at the end, and put in between the toothed cylinders A,B, it is drawn through on the other side, and slit into several pieces, or strings. And then, if there be occasion, any of these strings may be put through the plate mill with the same heat, and made into plates.

OPQ is the sheers for clipping bars of cold iron into lengths. V a cog in the axis of the water wheel. OP one side of the sheers made of steel and moveable about P. The plane LPR is perpendicular to the horizon. When the mill goes about, the cog V raises the side OP, which, as it rises, clips the bar TQ into two, by the edges SP; RP.

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1 From William Emerson, The Principles of Mechanicks, second edition, corrected and enlarged, Plate xx, London, 1758, (the following description is taken from the same book, pp. 251–252); reproduced by Rhys Jenkins, in Engineer, vol. 125, p. 488. London, 1918 — A slitting mill which differed by having the two water wheels at one side, is reproduced by Swedenborg, Tabula XXIX, in 1734. Both types are represented in the drawings of Christofer Polhem's slitting mills, of 1746, Nova Tr., vol. vii, Plate iii.

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All the engine, except the water wheels E, F, is within the house. Some further details are supplied by an eye-witness who in 1755 described a slitting mill on the river Rea at Birmingham which had been erected in 1702. By mechanical shears (OPQ in Emerson’s description) the bar was cut into lengths of about 1 foot each. These pieces were put into a furnace (not mentioned by Emerson) and heated red hot. Then they were drawn out by ‘a Couple of Steel Rollers’ to the length of about 4 feet and with a breadth of about 3 inches. After this, they were immediately passed through the cutters and slit into about eight square rods each.¹

A characteristic of the English rolling and slitting mill which distinguished it from those of other countries, e.g. Sweden, was the use of a single furnace for heating.² The English method saved both fuel and labour.

The waste of iron incurred in the process of slitting remained in Britain approximately the same.³ The capacity of the mill in the first half of the seventeenth century can be deduced from only very few examples; in 1634, Richard Boyle claimed that his mill at Lisfinny produced from fifteen to twenty tons per week, and production figures do not seem to have been higher in the Midlands, judging by the figures for the slitting mill on the river Tame at Bustleholme between Walsall and West Bromwich in Staffordshire, in 1623.⁴

A comparison of the two mills discloses to some extent why Boyle failed in Ireland while the slitting mill expanded in England. It was not owing to lack of demand, for Boyle had an offer from merchants in Staffordshire and Cheshire to buy all the iron he could draw into nail rods to be sent to Chester and other parts on the west coast of England. His nail rods, however, turned out to be of inferior quality, not only because of bad workmanship but also because of the inferior bar iron used. On the other hand, at Bustleholme, as shown by the above-mentioned agreement with Foley, bar iron of better quality was

² The term ‘steel rollers’ refers to the surface formed from a sheet of steel welded onto the body of the roller (cf. Joth., p. 237). With the slitting rolls—or cutters—the projecting rings only were of steel.
³ A cast-iron roller produced at Heathfield furnace, Sussex, in 1727, had a weight of 1 ton 6 cwt., Sussex AG, vol. lxxvii, p. 29.
⁵ The waste or loss of iron was 4½ lb. in 1 cwt. at Lisfinny, Ireland, in 1634, which was considered somewhat above normal and explained as caused by insufficient heat in the furnace, Cork MS, vol. 17, No. 185. At Colnbridge, Yorkshire, it was 3¼% (approx. 3 tons 9 cwt. loss in 1004 tons of bar iron) in 1710, Neusc. Tr., vol. xix, pp. 73-74.
⁶ Chatsworth, MS 78, p. 754.—In an agreement made with Foley by the lessees of the mill at Bustleholme, the former was obliged to supply at least 6 tons of iron (of long weight, i.e. 120 lb. per cwt. instead of 112 lb.) per week which was considered the minimum required to keep the mill going, PRO, Chancery Proceedings, Chas. I, F15, No. 12. The mill was still in operation in the late eighteenth century, J. Reeves, The History and Topography of West-bromwich, p. 114. London [1836].
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employed, such as ‘blend metal’ produced from ores in the districts of Wednesbury and Darlaston, from which rods suitable for tools and nails were made, and ‘tough’ iron for the best work.¹

In the course of the seventeenth century more slitting mills were built in the Midlands and farther afield.² The increase, however, was very gradual and was never great. In the early eighteenth century probably not more than twenty slitting mills as a maximum were operating simultaneously in England.³ The small number should not be regarded as a sign of backwardness in the iron industry in England. Even at Liège, which may have been the birthplace of the improved type of combined rolling and slitting mill used in the seventeenth and eighteenth centuries, their number was not more than eleven in 1703, and in Swedenborg’s days (in 1734) they were still rare in the district.⁴ England, according to a statement made in 1785, had only sixteen slitting mills in the late eighteenth century, and Ireland eight, but Scotland is not referred to at all. ⁵

The small number of mills in Britain at such a late date is rather perplexing, considering the considerable advantage the mill had over the hammer. In the manner described by Emerson the mill could draw out from ten to twenty bars of hoop or sheet iron in the same time in which the hammer made one only.⁶ There were, however, serious handicaps by which the evolution of the mill was impeded. The wooden supports and framework, in which the rolls were set, were not strong enough to allow for more powerful machinery. Even if that had been possible, there would still have been insufficient motive power, since the water wheel was the only means of supplying power.⁷ It was

¹ See footnote 4 opposite.
² In Cannock Wood, Staffordshire, mentioned first in 1652, and still operated in 1707 (Stafford, Wm. Salt Library, D i 1734, Leases Cannock No. 4), at Renishaw, Derbyshire, one year later, (Central Library Sheffield, Beauchief Muniments, No. 80), Wolverley, Worcestershire, mentioned in 1679 (Kidderminster Public Library, No. 1510). A forge at Rotherham, Yorkshire, was converted into a slitting mill in 1666–67 (Rotherham, Public Library, S.C. 16926).
³ In addition to the six mills in England previously referred to, there were three in Worcestershire, and four in Staffordshire (Johnson, pp. 130–139; 146), one in Birmingham (see p. 310, note 1) and a second erected at Nechells Park in 1746 (Kidderminster Public Library, MS 142), further four in south Yorkshire (Raistrick, in Nesc. Tr., vol. xix, pp. 71–77), and one mill each at Pontypool, Monmouthshire, probably in operation in 1692–93 (Johnson, p. 145), at Lidney, Gloucestershire (CRO, Gloucester, D421, T, 69), at Willsbridge, parish of Bitton, Gloucestershire (H. T. Ellacombe, History of the Parish of Bitton, pp. 111, 231, Exeter, 1881–83), discontinued in 1811 (Nesc. Tr., vol. vii, p. 52), at Ynyspenlwh, near Swansea, Glamorganshire (E. H. Brooke, Chronology of the Tin Plate Works in Great Britain, p. 169. Cardiff, 1944).
⁷ The water wheel of the slitting mill differed not much in dimensions from that of the power hammer. In John Smeaton’s designs, made in 1765 for Kilnhurst Forge near Rotherham, Yorkshire, and preserved in the Library of the Royal Society in London, the wheel of

Y—H.I.S.
only when the water wheel gave place to the steam engine in the 1780's that the potentialities of the slitting and rolling mill could be developed more efficiently.¹

FORGING OF ANVILS AND ANCHORS

Anvil forges

At the power forges cast-iron anvils were in general use. The iron of the blooms coming from the finery to be hammered into bars was not very hard, nor did it require to be beaten out very thin, yet cast-iron anvils cracked frequently and had to be replaced by new ones. In the manufacture of steel objects, in particular knife blades, cast-iron anvils were not firm enough to stand the hard and prolonged beating which was required. Anvils or stithies for forging cutlery however were made of cast iron in the sixteenth century.² Blacksmith's anvils of cast iron were still produced in the seventeenth and eighteenth centuries, in particular in Sussex.³

In the late seventeenth century a special process for producing more suitable anvils for blacksmiths and cutlers began to be employed; it was conducted in anvil forges. At the end of the sixteenth century and in the early seventeenth, several forges for the making of blacksmith's anvils, the average weight of which was 150 lb., were operating in the Forest of Dean area, at Gatcombe on the Severn, north-east of Lydney, at Lydbrook, and at Ruerdean. The anvils were made of scrap iron and slag (from the Forest), and were much more solid then either cast iron, or even wrought iron, anvils. The surface of the anvil was 'steeld', i.e., a layer of steel was welded onto it, amounting to about one tenth of the total weight of the finished anvil. The annual output of the anvil forge at Gatcombe, was 87 anvils in 1699-1700. Thirty-one of these were sent to Bewdley, probably to be sold to, and distributed among, blacksmiths and cutlers in the area of Birmingham and Dudley. Forty-two went to Bristol.⁴

the slitting mill was 18 feet high within the rim and 4 feet 4 inches wide, while the hammer wheel was 15 feet high and 6 feet wide.

¹ Ashton, pp. 74-75. John Wilkinson was the first who harnessed a steam engine to a rolling and slitting mill in 1786, Raistrick, Dynasty, p. 226. The mill was at Broseley, in Shropshire, Thom. Cowper, The Emporium of Arts and Sciences, new series, vol. 1, p. 239. Philadelphia, 1813.

² At Rievaulx furnace, in 1591, 'one casten steth' was produced and sold to Robert Edmundon, and in 1592 another to Lancelot Smyth of Barton, in Westmerland; the weight of each stithy was 14 cwt's. Be., Nos. 529 and 530.

³ At Kilmackee furnace, County Waterford, Ireland, three 'smith's anvils' each of 1 cwt. were cast in 1624. Cork MS, vol. 14, No. 257. In an inventory of Frant forge, Sussex, of 1652, 'one smith's anvil of cast Iron' is mentioned, Sussex AC, vol. xxxii, p. 99. At Heathfield furnace, Sussex, '1 Blacksmith anvil' weighing 14 cwt's. was cast in the campaign of 1769-70, Fuller MSS. Battle.

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Anchor smithies

In the last years of Henry VIII’s reign foreign iron, in particular Spanish, was considered superior to English iron for the manufacture of anchors. In 1546 an order to make 55 anchors for the English Navy was placed with Dutch anchor smiths who, however, were so busy that they could not promise to make more than one anchor per week. Even these were to be made of ‘Ames’ iron, i.e. iron produced in the district of Amiens in northern France, which was not of quite as good quality as Spanish iron. The difficulty of procuring the desired amount from Holland led to an attempt to buy anchors in the German ports of Bremen, Hamburg, and Lübeck.¹ The demand for foreign iron, preferably Spanish, for the use of the Royal Navy continued in the seventeenth century. In Admiralty contracts from 1661–70 the stipulation was made that only Spanish iron should be employed in the manufacture of anchors. In orders during the following fifty years two-thirds were required to be of Spanish, and one-third of Swedish, iron. An exception, however, was made during the war of the Spanish Succession, from 1701–13, when the anchors were made entirely of Swedish iron, Spanish iron being unobtainable.²

In the same period anchors for the merchant fleet were manufactured in English anchor smithies, e.g., at Newcastle-on-Tyne in 1650.³ At large ports such as Liverpool the manufacture of anchors was extensive. A considerable amount of the bar iron required came from the forges in north Lancashire. In 1759, when an anchor smithy was added to the forge at Backbarrow, in Lancashire, seven anchor smiths from Liverpool were engaged. The smithy which was worked with mineral coal yielded no profit and closed down twenty years later.⁴

English iron replaced that for the Navy from Spain and Sweden after 1784, when Cort’s early experiments on puddling and rolling into bars proved so successful that his iron was directed to be employed exclusively for naval anchors and chains.⁵

³ PRO, Eschequer Depositions by Commission, 1650, Mich. 5, p. 8 — In the vicinity of London at least eight anchor smiths were active in 1677, Yarranton, Part 1, p. 63.
⁴ Fell, p. 233.
CHAPTER XVIII
STEEL

ESTABLISHMENT OF STEEL WORKS IN THE SIXTEENTH CENTURY

WITH the growth of industry and the increase of population in sixteenth-century England, the demand for steel became greater than ever before. Inland production was not sufficient to satisfy the demand, and this sometimes led to deceptions such as forging high-quality iron from Bilbao in Spain into a shape resembling a gad of steel, and selling it as steel proper. Most steel was imported from abroad, in particular from Germany via Cologne. As late as 1577, foreign steel was considered superior to the English product. The growing demand, however, stimulated English producers to challenge foreign production by setting up steelworks in the country.

The first attempt known from documentary evidence, was the erection of a steel forge in 1509 by Claudius Robynson, in Ashdown Forest, near Hartfield, in Sussex. It was worked by water power from a rivulet in the vicinity, and is mentioned last in 1603–04. The capacity of production was estimated in 1539 at from forty to fifty tons per annum.

The next known attempt was made by Sir Henry Sidney, who erected a furnace for the production of raw steel in Glamorganshire, and also steel forges at the former Cistercian Abbey of Robertsbridge in Sussex, and at Boxhurst, in the parish of Sandhurst in Kent, in 1565. Rhys Jenkins has elucidated the history of these works.

2 "As for our steele, it is not so good for edge-tools as that of Colaine", W. Harrison, A Description of England, Part ii, New Shakespeare Society, Series VI, p. 76. London, 1887.
3 PRO, Ministers’ Accounts of the Duchy of Lancaster, Bundle 455, No. 7331 — Ibid., Bundle 447, No. 7185; Bundle 448, No. 7420.
4 PRO, Exchequer Treasury of the Receipt, Forest Proceedings, No. 197.

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however, more evidence in respect of the early beginnings of Sir Henry's undertakings, and also, from sources in foreign archives, an explanation of the causes of their failure after a short period of success.

On 8th August 1565, Queen Elizabeth granted by Letter Patent, a 'licence' or privilege to Sir Henry Sidney, Edmund Roberts of Hawkhurst in Kent, merchant, Rauke Knight, and David Willard to introduce into the Realm of England, Ireland, and Wales, during twenty years following, 'so manye strangers or alyens,' as the patentees 'shall entertayne onelie for the searchinge, digginge and conveyinge of the mynes ever (i.e., mine ore) and stone for the makinge of steele and iron wyer'. The number of foreign workers was limited to one hundred.¹

It is doubtful whether Sir Henry, the first of the four partners mentioned in the licence, took more than a capitalist's interest in the enterprise, as his duties as Lord Deputy of Ireland and President of Wales kept him away from Kent and Sussex for most of his life. His wife, however, Lady Mary, daughter of John Dudley, Duke of Northumberland, was interested in metallurgy, as is demonstrated by her active interest in William Medley’s attempt to convert iron into copper by heating it with blue vitriol.² The partnership of Edmund Roberts was most valuable on account of his position in the iron trade. For many years before the erection of these steelworks he had been a purchaser of the iron produced at Sir Henry's ironworks erected at Robertsbridge in 1541.³ Roberts was also a member of the Merchant Adventurers, the great commercial company who in the sixteenth century sent their ships to European ports, from the Mediterranean to the Baltic.⁴ Knight and Willard were partners for only a short time. David Willard, first mentioned as an 'ironmaker' of Tonbridge in Kent, in 1555,⁵ must have withdrawn from the partnership at a very early date, as he was never mentioned as a partner in subsequent documents concerning the steelworks. Rauke Knight, General Receiver of Sir Henry's English estates, died in 1567, and was succeeded in the partnership by his wife Johane.⁶ Consequently from 1568 Sir Henry Sidney and Johane Knight owned half the steelworks, and Edmund Roberts the other half.⁷

The next tasks of the partners were: (1) To obtain a monopoly for the sole production of steel in England, and (2) to procure foreign workers according to the above-mentioned privilege of 1565. In respect of the first task they were completely unsuccessful. Two Bills

¹ The licence is inserted in a Letter Patent of 7th July 1568, PRO, Patent Rolls, Elizabeth, No. 1052.
³ See, Nos. 151 and 152; Straker, p. 310.
⁵ Ibid., p. 94. In 1574, Willard worked furnaces and forges near Tonbridge, Straker, p. 222.
⁶ See, Nos. 152, 154, 385.
⁷ See, No. 385.
submitted to the House of Commons, one for ‘making of steel and plates for armour’, the other for ‘making of steel and iron wire’, were dealt with in 1566, but neither of them passed the House of Lords.¹ A monopoly excluding competition, aimed at by the two Bills, was not only refused to Sir Henry and his partners, but was granted, in respect of the manufacture of wire, to William Humfrey, who set up the wire works at Tintern Abbey, in Monmouthshire.

The preference given to Humfrey has a political background. Humfrey was in the closest contact with the leading statesman of the Realm, the Chancellor and Secretary of State, William Cecil, Lord Burghley. From the lengthy correspondence between the two, preserved in the State Papers Domestic of the Public Record Office, it is quite evident that Humfrey was Lord Burghley’s adviser in technical and metallurgical matters. On the other hand, Sidney, by his marriage with Mary Dudley, was brother-in-law to Robert Dudley, Earl of Leicester, who was the favourite of Queen Elizabeth for thirty years. The rivalry between the powerful statesman and the favoured courtier naturally extended to their adherents. Burghley never ceased to regard Henry Sidney with aversion and distrust. He even feared that Leicester might endeavour to have Sidney made Secretary of State in place of Burghley.²

When the manufacture of wire, which had been the principal object of the new enterprise, had to be abandoned to a more successful competitor, production was limited to the manufacture of steel. For this purpose, large numbers of foreign steelmakers were engaged. Between 9th October 1565 and May 1566, they came to England in nine different groups, numbering altogether at least fifty-five steelmakers, some accompanied by their families.³ The country from which they came, is in the accounts called the ‘high country’, whence they travelled to England via Cologne. The term ‘high country’ points to the mountainous area of southern Westphalia, containing the Sauerland, under the rule of the Archbishops of Cologne, and north of it, the Mark, ruled by the Dukes of Cleves and Mark. This assumption is confirmed by the family names of the steelmakers⁴ which occur frequently in contemporary documents in the State Archive at Münster, in Westphalia, concerning Sauerland and Mark.

Both districts were the home of an ancient steel and wire industry. In respect of trade with England two towns were foremost: Attendorn and Breckerfeld. Citizens of Attendorn are mentioned as pursuing their trade in England as early as 1328.⁵ In sixteenth-century Germany it

¹ S. D'Ewes, The Journals of All the Parliaments During the Reign of Queen Elizabeth, pp. 126, 132, 133. London, 1682.  
³ Pe., No. 384.  
⁴ Rhys Jenkins, loc. cit., ‘List of names’, p. 34.  
was believed that the Steelyard in London got its name from Breckerfeld steel exported into medieval England.\(^1\) This is definitely a patriotic exaggeration, as the prosperity of the steel industry of Breckerfeld and its surroundings commenced only about 1415; but steel export from Breckerfeld was certainly very considerable in the fifteenth century.\(^2\)

The manufacture of steel at Robertsbridge and Boxhurst began early in December 1565; the wholesale trade began on the 20th of the following March and extended to London, Coventry, Ipswich, York, Ireland, and Wales.\(^3\) The effect in the English steel market was felt immediately by the German steel traders. Moritz Zimmermann, Alderman of the Steelyard in London, reported in a letter dated the 9th August 1567,\(^4\) to Dr. Sudermann, Syndicus of the Hanseatic League in Cologne, on the status of the English steel market. There is no prospect, he says, of the contract for the import of steel from Breckerfeld to London being renewed after its expiry on 1st August. More than 300 barrels of imported steel are still unsold, and there is no chance of their being sold, because, according to his information, the English have found means of manufacturing steel as good ("so guett sthaell") as the steel from Breckerfeld. This, he continues, must be a serious blow to the steel merchants of Cologne, as the London ironmongers will not venture to buy more steel than can be immediately sold.

Zimmermann's letter reveals the great initial success of the steelworks at Robertsbridge and Boxhurst. It also reveals the cause of the complete failure that soon followed, viz., the extensive import of steel from countries bordering on the Baltic sea, particularly from Sweden. These imports in the latter part of the sixteenth century were effected by the Merchant Adventurers, who gradually supplanted the merchants of the German Hanseatic League in the English steel market. A single enterprise such as Sidney's steelworks had no chance of competing with such powerful rivals. Steel, imported from abroad, this time by English merchants, entered the London market in large quantities, and prevented the steel produced at Robertsbridge and Boxhurst from being sold at reasonable economic prices. The result was a rapid fall in sales and prices, which is noticeable in the surviving accounts. The annual sales of steel being 166-8 firkins in 1566 (sale price per firkin £7 in March, average price £6 10s. from March to August) fell to 51 firkins in 1568 (sale price £6), and to 18½ firkins in 1570–71 (sale price £5).\(^5\)

\(^1\) A. Meier, *Geschichte und Urkundenbuch des Amtes Breckerfeld im Landkreise Hagen (Westfalen)*, p. 128. Hagen, 1908.
\(^3\) Pe., No. 384.
\(^4\) The letter is preserved in the Historical Archives of the City of Cologne, printed by A. Meier, loc. cit., p. 224.
\(^5\) Pe., Nos. 384, 385, and 147 (for 1570–71; cf. Rhys Jenkins, loc. cit., pp. 35–36). The weight of the firkin cannot be ascertained; Jenkins (p. 35), assumed "about 6 cwt," but it seems to be more. In "Accounts, 1567–68" (No. 385) it is stated that in four months 57 firkins were made, but only a little more than 17 were sold.
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Production appears to have ceased shortly after 1572, when the works still had its own clerk; there is no reference to later production in any subsequent account. In the same year, 1572, a payment to Edmund Roberts on account of his partnership is mentioned for the last time. Later, Edmund Roberts had a gunfoundry at Abercarn in Monmouthshire, which he still possessed at the time of his death, about 1581. He died 'a poor man' leaving debts of £2700 'at the least'—a considerable sum in those days.²

Despite the very short period of prosperity, the two steelworks at Robertsbridge and Boxhurst are notable as an early attempt to make England independent of steel imported from abroad.

EARLY METHOD

The ancient method of producing steel directly from suitable ores survived in the sixteenth century and later still. Mines in which such ores were exploited were sometimes called steel mines.³ Quite early in the sixteenth century ironmasters were well aware of the existence of these ores. The 'mines of yron and stele' which Michael Wynston in 1550 claimed to have discovered in the Royal Forests of Exmoor and Dartmoor, were probably mines of spathic ore, still being exploited in the nineteenth century on Exmoor, the ore being shipped from Lynmouth to south Wales.⁴ There is however nothing to show whether Wynston had any success in steel-making.

Fifteen years later, raw steel was obtained directly from the ore in a blast furnace in Glamorgan, probably on the left bank of the river Taff south of Castel Goch and near Ivy house, Tongwynlais. The partners who owned the furnace also owned the steelworks in Sussex and Kent, but from 1567 Sir Henry Sidney and Edmund Roberts were the only co-partners. To begin with the furnace in Glamorgan had been operated solely for the production of pig iron.⁵ The raw material for the above-

¹ Pe., Nos. 147 and 378 — The Robertsbridge works is mentioned in a survey of the Manor dated 1609, preserved only in a transcription of 1783 (BM, Add. MS 5680, fol. 91). Jenkins (p. 18) doubts whether the establishment was still in operation in 1609; perhaps the description refers to an earlier period when the German steelworkers were still working.
² E. G. Jones, Exchequer Proceedings (Equity) Concerning Wales, Board of Celtic Studies, University of Wales, History and Law Series, No. IV, p. 257. Cardiff, 1939.
³ 'Miners of steel' at Llantrisant, Glamorgan, are referred to as late as in 1631, Wilton, Muniments Box 28, No. 516.
⁵ Furnace and forge books of 1564 referred to but not preserved, Pe., No. 986 — The position near the river Taff is indicated by the use of a boat for shipping the products to Cardiff whence they went by sea to Sussex, Pe., 388 — NLW., Bute Muniments, Parcel B, No. 2, Box 91 (Survey of 1625, referring to a furnace in the parish of Whitchurch and a forge in the parish of Machen, both worked by Thomas Hackett) — Cardiff, Public Libraries, MS 5120, pp. 1 et seq. (lease of 1706) — See also E. L. Chappell, Historic Melengriffith, p. 29. Cardiff, 1940.

mentioned steelworks first came from Chingley furnace, parish of Goudhurst, Kent, in 1565 but perhaps the pig iron from this furnace turned out to be unsuitable, for in the same year miners ('Bergeknihthen', in the English document instead of the German 'Bergknappen') were brought over from Germany. They stayed in Wales during July at the end of which they went home again. Shortly afterwards, 'Dutch' (i.e. German) founders were taken to Wales. Miners and founders had apparently been sent for to test the ore in the vicinity of the furnace for its suitability for steel-making. That they were successful in finding suitable material is shown by the fact that from December 1565 onwards all the steel plates for Sidney's steelworks in Sussex and Kent were obtained from his furnace in Glamorgan.

The method of producing either ingots of raw steel, termed 'plates', or pig iron in the same furnace but at different times, emerges from accounts of the different proportions of ore, fuel and fluxes in the charge of the furnace. Per 'founday' (of six days), for producing steel plates, 32 loads of charcoal (35 for pig iron), 2½ loads of marl (4 for pigs), no limestone (1 load for pigs) were charged. The quantity of ore charged for producing steel plates (3 loads for 1 ton of metal) was greater in relation to charcoal than for pig iron (2½ loads), so that the metal should absorb less carbon. Average daily production was the same, i.e. 1 ton 6 cwts. 74 lb. in twenty-four hours.¹

The local ore was haematite, available in the immediate vicinity at Forest Fawr north of Tongwynlais. In all the ores found in the hills and mountains extending from Llantrisaint in the west to Rudry in the east the most important constituent is silica; present in various proportions.² The high proportion of silica in the ore required a considerable amount of fluxing agents for its liquation, which accounts for the proportion of marl and lime added. By using less of these agents in the charge for producing steel, the volume of liquefied slag in the slag bath was diminished, so that the metal was more exposed to the action of the blast.

There is not much evidence about the method used at the steel forges at Robertsbridge in Sussex, and at Boxhurst in Kent. The implements used by the Westphalian steelmakers were: chisels, axes, an auger, grindstones, forms (i.e. work benches), hammers and anvils. One item refers to the 'setting up of a fornese'. According to an inventory of 1609, at which date operations had already ceased for some time, there had been at least ten forges in the buildings of the former abbey at Robertsbridge. In the same inventory 'rollers' are referred to.³ Rollers

¹ Estimate of 1568, Pe., No. 988 — Marl consists mainly of clay mixed with carbonate of lime.
served for the plating of the steel ingots previously heated in the furnace. Cutting implements may also have been manufactured, as is indicated by the reference to grindstones, but by far the greatest production was of steel bars. Since the steelmakers came from the Westphalian country of the Mark in the south-east of Westphalia and bordering on the district of Siegen, it may be assumed that they used the same methods as in their native country.

The Westphalian steel forge in which the raw steel cakes or plates were refined differed from the Walloon forge used in England for the refining of iron, in as much as melting and reheating was conducted in the same hearth.

According to a late description the fireplace of the hearth was 2 feet square, i.e. smaller than that of the iron forge, but deeper. The sides were protected by cast-iron plates, but the bottom was of fire-resisting sandstone instead of cast iron. The tuyere was placed higher and was less inclined into the fireplace. Blast was produced by a pair of bellows 8 to 9 feet long. The slag was allowed to rise a few inches above the raw steel which was thus not directly exposed to the oxidising blast. When the steel was considered to be refined sufficiently it was taken to the power-hammer, the iron head of which weighed from 5 to 6 cwt. It was first hammered gently and then cut radially into 5 to 8 pieces, which were reheated successively at white heat, turned several times, and finally hammered out. The loss in weight incurred in the whole process was usually one quarter. Water power was apparently not employed at Sidney's steel forges, which is by no means exceptional. At Siegen in Westphalia, for example, the steelsmiths working in the town did not use water power either.¹

The German method practised in Sidney's short-lived enterprise had no influence upon the development of steel-making in England. The Westphalian steelmakers were in England for less than a decade and left no traces either in records or in parish registers. Perhaps they were dissatisfied with the raw steel from ores which in no way came up to the standard of the ore employed for steel production in their native country. The supply of steel in England subsequently depended on imports and a few established English steel forges, such as the one in Ashdown Forest, operated from 1509 to 1603.² Another Sussex works was the steel forge in the parish of Warbleton, reputed to have been on the property of Richard Woodman who died in 1557.³

That steel was made in sixteenth-century England is implied in

¹ Eversmann, loc. cit. (1804), pp. 44, 203-205 (somewhat different from the later description by Percy, pp. 779-782) — H. Schubert, Geschichte der Nassauischen Eisenindustrie, p. 14, Marburg, 1936 (no water power as late as in the 1560's) — For a picture of a German steel forge see Agricola, p. 425 (reproduced Joh., Illustration No. 109).
² PRO, Ministers' Accounts of the Duchy of Lancaster, Bundle 455, No. 7331. — Ibid., Bundle 447, No. 7185; 448, No. 7420.
³ Straker, pp. 179, 378.
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Harrison’s statement of 1577, according to which English steel (‘our steele’) was sold frequently instead of the superior steel imported from Germany, and was employed in the manufacture of edge-tools.¹ At Woodstock, in Oxfordshire, the manufacture of such tools can be traced back to the reign of Queen Elizabeth I by a reference to ‘Woodstocke work’ in John Marston’s Satyres of 1598, and inferred from the presence of cutlers at the same place.² The principal centre of the cutlery trade, however, was in the district of Sheffield in Yorkshire. John Leland in his travels of 1535-43 found ‘veri good smiths for all cutting tools’ at Rotherham near Sheffield and ‘through all Hallamshire’.³ Towards the end of the century production of native steel is shown by the ‘steel money’ paid to the Lord of the Manor of Sheffield in 1589 and 1590. This was apparently a customary payment by smiths who preferred to make their own steel instead of purchasing it from the Lord’s storehouse at Sheffield. Some of the ores in the West Riding of Yorkshire were very suitable for producing steel in the bloomeries, since they contained a fair amount of manganese, little phosphorus and mere traces of sulphur.⁴

Steel obtained from manganese-bearing ores in the bloomery process was produced in Ireland also, where bog ores were employed. In 1609, commissioners of the City of London travelled in Ulster with the object of surveying districts allotted for plantations. At Toome, in County Antrim, they examined the ore and employed a local smith to make iron from it. They were greatly impressed by the skill of the smith who not only made iron but converted it into steel within less than one hour. One of the city’s agents who had some knowledge of ironmaking reported that ‘this poor smith has better satisfied him than Jarmaynes (i.e. Germans) and others that presumed much of their skill’.⁵

CEMENTATION

For steeling those agricultural and mechanical tools for which steel was particularly required, the local smiths used their own stocks of materials

¹ ‘As for our steele, it is not so good for edge-tools as that of Colaine’, W. Harrison, A Description of England, Part II, New Shakespeare Society, Series VI, p. 76, London, 1887.
³ Lloyd, loc. cit., p. 90 — The theory that the cutlery trade and steelmaking were improved by refugees settled by the Earl of Shrewsbury in the Sheffield area after the repression of Protestants in the Netherlands in 1569-72 cannot be corroborated by any contemporary evidence; the earliest account of their coming occurs in a newspaper of 1803, ibid., pp. 101-102, 104-105. Other refugees settled at Stamford, Lincolnshire, in 1572, are described as being ‘skilled in all manner of worrakes in steele, iron and copper after the fashion of Nuremberg and other places beyond the sea’, J. Strype, The Life and Acts of Mathew Parker, vol. III, pp. 211-212. Oxford, 1821. The reference to Nürnberg which in those days was famous for its metal-working crafts would suggest that they were craftsmen manufacturing metal ware rather than producers of the raw material.
without having recourse to imported steel. The two ancient methods of welding steel strips on to the iron body of the implement, or of steeling the finished implement by case-hardening were both at the smith's disposal. Steel for strips could be produced in a bloomery by leaving the bloom in the course of its formation longer in contact with charcoal and, at the same time, exposing it less to the decarburising blast from the tuyere which for this purpose was set less inclined. A simple method of case-hardening could be employed in any blacksmith's forge in the same way as described by Theophilus in the Middle Ages. It was still practised in England in the seventeenth century, although already on the wane at that time. Joseph Moxon, the first English publisher of a series of technical handbooks, recorded that 'formerly' most rasps, i.e. coarse files, had been thus made and were still made 'sometimes' by file-cutters 'for cheapness'.

Moxon gives a detailed description of the process. Cow horns or hoofs were first dried in an oven and then pounded into powder which was then mixed with sea salt and stale urine or wine vinegar. A part of the mixture was laid on loam, the iron was laid upon, and covered all over with the mixture. Then, with iron and mixture encased in the loam, the whole was laid on the hearth of the forge so as to dry and harden the loam cover. Then it was put into the fire and heated to a bright red heat (about 900°C), but not more because otherwise the 'quality' of the mixture would burn away and leave the metal as 'soft' as before. At the end of the process the iron was quenched in water.

Steel produced in Britain varied very much in quality: A passage in Laneham's drama 'The Cobbler of Canterbury' of 1590 runs: 'Women's wittes are like Sheffield knives, for they are sometimes so keene as they will cutte a haire, and sometimes so blunt, that they must goe to the grindstone'. The inferior quality of most British steel was due to the ores employed, the majority of which were low-grade phosphoric ores. Phosphorus is an objectionable element in steel as it weakens it and makes it brittle.

The primitive method of surface cementation or case-hardening, as described by Moxon continued in the seventeenth century. Cementation was used by the smiths in the manufacture of coarse files, and by gunsmiths for hardening the barrels of guns. It was also applied in the manufacture of tobacco boxes, buttons, and heads of walking sticks. All these objects were valued higher after cementation, because the iron took a better polish.

An alternative for loam was plate iron in which the mixture of

1 Rogers, vol. iv, p. 401.
2 J. Moxon, Mechanick Exercises, or the Doctrine of Handy-Works, p. 54. London, 1677 — The antiquity of the process was recognised by early English writers who dealt with the subject, such as Plot, p. 373, and Lewis, vol. v, p. 139 ('has been long known to the workmen'). About Theophilus' method see above p. 120.
3 Lloyd, loc. cit., p. 95.
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carbonaceous matter was encased. A different method was used at Wolverhampton. The carbonaceous mixture was reduced to powder, in which the red hot iron was rolled and then returned to the fire. The effect of all these methods was no more than a slight cementation of the surface, which did not penetrate deeper than to 'the thickness of a shilling'. This was considered sufficient, since the main object was to prepare the article for polishing 'without scaling'.

Around 1600, the price of imported steel increased on account of monopolies granted for its importation. Public indignation rose against the monopolies, with the demand for greater independence of foreign imports by an increase in home production. The first attempts in this direction were made by two Englishmen, William Ellyott and Mathias Meysey, who in 1614 obtained a patent granting them for twenty-one years the sole right to convert iron into steel in a reverberatory furnace. The patent was confirmed two years later.

The process claimed by Ellyott and Meysey as their invention was not a complete novelty. It was practised on the Continent at about the same time, in the Low Countries as well as in Germany. In the English patent only a few details of the process are mentioned. The iron was embedded in a mixture of ingredients, the nature of which is not disclosed, and put into pots which were carefully closed to exclude the access of air. The pots were placed in a reverberatory, or air, furnace. The fuel for generating the temperature required in the furnace, was mineral coal, according to the second patent. The steel cemented in the furnace was consolidated by hammering. Judging by the process used in Germany, the mixture used for cementation was carbonaceous matter mainly consisting of charcoal. The pots were apparently of clay. The steel produced was subsequently called blister steel from the blisters occurring on its surface. This method of cementation was a decided improvement technically and commercially. The closed vessels guaranteed a cementation more complete than in the earlier processes,

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1 Plot, p. 373.
3 'Performed by means of a reverberatorische furnace with pots luted or closed to be put therein containing in them certain quantities of iron with other substances, mixtures and ingredients, which being in the said furnace brought to a proportion of heat doth make or convert the same iron into steels', PRO, Patent Rolls, 12 Jan., Part i, No. 15 — Abstracta; D. Browlie and Baron de Laveleye, 'The History of the Cementation Process of Steel Manufacture', J.R., vol. cxxi, pp. 457–459, and Rys Jenkins, in Neue Tr., vol. iii, pp. 18–19.
4 In the bishopric of Liège in 1613 (no other evidence but the patent), D. Browlie, etc., loc. cit., pp. 469–472. At Schellahausen, in Hessen, a small steelworks was erected in 1608 by Antonius Zeller, who had made his first attempts near Nürnberg in 1601, H. Schubert, 'Antonius Zeller und die Anfänge der deutschen Zementstahlherstellung', S.B., vol. 50, pp. 1473 et seq., see also F. M. Ress, ibid., vol. 75, pp. 979–980. In 1628, the same process was claimed as an 'invention' by a steelmaker Johannes Saccus and practised from 1637 at Lönberg, Lahn, H. Schubert, in Vom Ursprung und Werden der Budens'schen Eisenerze Wetzlar, vol. 1, p. 77. München, 1938.
though still confined to the surface. The use of several vessels at a time was an economy, as was the use of mineral coal as a fuel instead of the more expensive charcoal.

A few years after the grant serious complaints were lodged against the patent. They were directed firstly against the disadvantages arising from the prohibition of steel imports imposed in favour of the patentees, but also against the quality of the steel they produced. The complaints came from ironmongers, blacksmiths, locksmiths, scythesmiths, cutlers, and gun-makers of London, who all protested against the bad quality of the steel. The complaints were finally rejected in 1618 by the Attorney General as a conspiracy against the patentees, but they do not seem to have been quite without foundation. Although some foreign merchants were among the signatories, the opposition was so widespread that it can hardly be dismissed as an action dictated by mercenary motives and national prejudice, especially as the complaints against the inferior quality of the steel were confirmed by the king’s gunfounder Thomas Browne. He testified that he had tested it and found it ‘naught’ and wholly unfit.1

When the complaints began to be discussed in the autumn of 1617, one of the defendants expressed his conviction that it was rather Sir Basil Brooke than Ellyott and Meysey who was behind the legal proceedings against the complainants. This is the first reference to Sir Basil in connection with steel-making. He was one of the lessees of the king’s ironworks in the Forest of Dean. When his lease expired in 1635, he made a statement about his past services rendered to the country. One of them, he claimed, was having ‘settled’ the new invention of making steel in the Realm. Neither the date nor the place of the steelworks erected by Sir Basil Brooke is known, but it seems to have been somewhere in the region of the Forest of Dean. The Meyseys were a family with property both in Worcester and Gloucestershire. So it is quite possible that Brooke was in partnership with Ellyott and Meysey when their patent was transferred to Brooke in 1620, and that he selected this district for a steelworks.2 This is also suggested by a reference to excessive consumption of wood in the Forest of Dean for steelmaking by the ‘late Patentees’, made by certain Frenchmen who applied for a patent.3 They were supported by Robert Fludd, a Doctor of Physics, who tried to upset Brooke’s patent.4 Fludd raised strong

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1 PRO, Star Chamber Proceedings, James I, Bundle 25, No. 17.
2 76, vol. 179, p. 254 — Cal. SPD, Charles I, 1635, p. 308. London, 1865 — The steelworks may have been at Linton which is in Herefordshire but not far distant from the Forest; the site of a former steelworks was discovered at L. at a place where a house called the ‘Steelworks’ still stands, Tr. of the Worcesters Naturalists’ Field-club, 1927-29, p. 241. Hereford, 1931.
3 The application is published, Tudor Economic Documents, loc. cit., vol. 1, pp. 322-324, but should not be dated ‘c. 1603-06’.
4 He may be identical with a Doctor Robert Fludd who was an alchemist and a prolific writer, best known by his Utriusque Cosmi Historia, published at Oppenheim in Germany in 1617-19.
opposition in London against the steel made by Brooke, and with success, for in 1620 a patent was granted to him and a Master John du Rochier, one of the French steelmakers patronised by Fludd. The project came to an end five years later when du Rochier died, and it is doubtful whether it had been successful. There is, however, no doubt that Sir Basil Brooke really made steel, as is shown by a statement of Thomas Fuller who called him 'the great steelmaker' in the county of Gloucester. Fuller was critical of contemporary English steel. He said that it is useful for the making of English knives, scythes, scissors, shears, etc., but 'fine edges cannot be made thereof' such as lancets for blood-letting, incision knives, dissecting knives, and razors. No artificer was able to make these of 'English steele', but must obtain the steel from Damascus, Spain, or Flanders.

Steel-making was well established in Sir Basil Brooke's days in the region of the Forest of Dean, and remained so long after his death. As late as 1677, his was considered better than any other English steel.

Not long after cementation began to be practised in England, steel-making was introduced into Ireland. In 1629, Richard Boyle was approached by one Thomas Ledsham of London. It is very likely that he was identical with that Thomas Letsome who claimed to have invented and perfected a method of making steel, for which he with two partners obtained a fourteen years' patent in 1626. In May 1629 a contract was made between Ledsham and Boyle, by which Ledsham was obliged to convert 21 cwt of bar iron into one ton of steel, while Boyle supplied iron and mineral coal. Subsequently a steelworks was erected at Ballintree, in County Cork. Nothing is known as to the process used, though the use of mineral coal suggests a reverberatory furnace. Boyle was not satisfied with the result, and Ledsham surrendered steelworks and stock in 1634. Production, however, continued, since a new lease was granted, but it is not known for how long.

Moxon refers to the production of steel in several English counties in 1677, viz. Gloucestershire, Kent, Sussex, and Yorkshire. The allusion to Kent and Sussex seems to refer to the activities of the Brownes who had furnaces at Brenchley and Horsmonden in the Weald of Kent and at Hawkhurst in Sussex in the seventeenth century. In 1673, John Browne began to utilise a patent granted in 1671 to the gifted Prince Rupert, a grandson of James I. A part of the patent was concerned with


\[2\] Moxon, loc. cit., p. 55; the fracture showed 'somewhat a coarse grain. But if it be well wrought and proves sound, it makes good edge tools, files and punches. It will work well at the forge and take a good heat'.

the Prince's 'invention' of converting into steel all manner of edge tools, files or other manufactured implements. His method is not known, but it seems to have been merely a case-hardening process. The date at which the process was introduced into the north of England is obscure, but it seems to have been between 1650 and 1660, and to have come from the Forest of Dean area. When in 1662 the cutlers, scythe-makers and other artificers of 'hard ware' in Hallamshire objected against the grant of a monopoly for steel to Charles Tucker of Rotherham, they alluded to the good steel formerly produced by Sir Basil Brooke. Three years later the objection was raised again by the 'makers of steele', cutlers, makers of scissors and edge tools in Hallamshire. By that time steel was possibly being made in or near Sheffield.\(^1\)

From the Midlands no evidence is available prior to 1682, in which year Ambrose Crowley senior owned a 'steel house' at Stourbridge. Crowley bought Swedish bar iron for conversion into steel. From Stourbridge steel-making extended to Birmingham, which became an important centre of steel production in the eighteenth century. By an estimate of 1737, 220 tons out of a total of 900–1000 tons of Swedish iron imported into England for steel-making, were consumed within ten miles of Birmingham. Around 1700 steel-making was introduced in the district of Newcastle-upon-Tyne, probably from Stourbridge by Sir Ambrose Crowley.\(^2\)

In the area of Stourbridge, from which the craft of steel-making spread, an important change had taken place by that time. Instead of English bar iron foreign bars, principally from Sweden, were employed as raw material for cementation, and these were thenceforth used in all the English cementation furnaces for more than a hundred and fifty years. This was a deviation from the original objective pursued by Ellyott and Meysey who intended to make the country independent of foreign imports of iron for steel-making. However this development was not solely on account of the relative cheapness of the imported iron, but also because of its better quality. A German metallurgist who was in Birmingham in 1768 explained the exclusive use of Swedish iron in the cementation furnaces of Birmingham by declaring that English iron during the process turned into slag.\(^3\)

\(^1\) *Nov. Tr.,* vol. iii, pp. 24–25 — Browne's furnaces: 'Archives of the Hutton family', CRO, Lewes. See also p. 325, note 1. If the steel wire referred to in the patent of 1671 really was produced, it would be the earliest evidence in this country. The next is from 1709, at which date it was probably produced at the wireworks of Tintern, BM, *Court Books of the Mineral and Battery Works*, vol. iii, p. 228. At Aachen, Germany, it is supposed to have been produced before 1600, *Joh.,* pp. 179, 249. Possibly, Prince Rupert obtained his knowledge in Germany before he came to England.


Steel

The home process, however, was improved to some extent. One improvement was the use of Stourbridge clay for the chests as they were called, in which the bars were cemented. Fire-resisting Stourbridge clay was the best clay obtainable in the country.¹

A few miles north of Stourbridge, in the tile-house of Bromley in Staffordshire, a cementation furnace was being operated by John Heydon in 1686. It was the first of its kind in England of which a detailed description exists.² It was the prototype of the cementation furnace subsequently used in the country.

![Cementation furnace diagram](image)

**Fig. 36.** Cementation furnace at Sheffield. Transverse section.

(a,a) chests or pots containing the iron bars embedded in charcoal; (b) fireplace with grate; (c) ashpit; (d,d) arched roof to confine the heat as much as possible to the chests; (e,e) fire flues; (f,f) domed roof of the exterior with low chimney (older type of furnace); (g,g) tall chimney (replacing f,f in the late eighteenth century). The passing of the flames is indicated by arrows.

From G. Jars, *Voyages métallurgiques*, vol. 1, Plate vi, Lyons, 1774, and Percy, p. 771.


—H.L.S.

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Steel

The cementation furnace at Bromley is described, in 1686, as cylindrical in shape and built of bricks, like a baker's oven at the top (d,d). It had a hearth or fireplace (b) with a grate. On each side and at the rear of the hearth, 'coffins' were placed, i.e. oblong chests (a,a) made of refractory clay obtained from Amblecote (just outside Stourbridge). In each chest bars, half a ton per chest, were laid, alternating with layers of carbonaceous matter and 'enclosed' by it all round. Before being placed in the chests the bars were broken into smaller lengths of 3 to 5 feet. The longest bars were laid in the chest at the rear of the oven, the shortest in those on each side. The firing of the furnace took from three to seven days, depending upon the quality of the coals used. Heydon claimed that a total cementation of the bars was achieved ('hardens whole barrs of iron quite through'). The secret of the process was the proper observation of 'the critical-minute' at which cementation was considered to be completed. It would be the moment at which the bars began to show signs of blistering on the surface.¹ The composition of the carbonaceous matter for cementing was kept secret by Heydon. The iron he used was exclusively Swedish or Spanish bar iron. The bars of blister steel when taken out of the conversion furnace were consolidated by a power hammer.

During the process it could happen that the iron carburised to a higher degree than desired, so that the steel became hard and brittle, and unfit for use. Such metal was termed 'oversteeled'. When quenched in a red hot state it was liable to crack to pieces in the water, and even if it came out entire, a blow of the hammer would shatter it. A correcting operation termed a 'second cementation' could, however, be carried out in the same furnace. The metal, placed in the chests, was surrounded with carbonaceous matter, in particular bone ash to which one-third of its weight of powdered charcoal could be added to expedite the process. If this process of second cementation was prolonged the steel gradually was reconverted into iron. A sign that the reconversion had been satisfactory was the appearance of a narrow coat of iron on the surface. Such a coat of iron was considered the principal advantage of the correcting process, and was in many cases desired by the workers because of the greater facility of filing the tools made of the metal. Steel thus corrected was a composition consisting of imperceptible gradations from the finest steel to iron.²

Blister steel was uneven in composition, and harder on the surface than at the core. It was good enough for the blacksmith. The hardest, i.e., the most blistered bars were used by the scythe makers who welded the steel on to the iron body of the scythe. The steelmakers, aware of the lack of uniformity, found it necessary to examine each bar after its

² Lewis, vol. v, p. 135.
withdrawal from the furnace. The test was effected by striking each bar with the pane of the hammer on a hollow anvil. Though suitable for many purposes, blister steel could not be used in the manufacture of articles which required the best metal.

A further improvement was achieved by the production of shear steel. To make blister steel more uniform in texture, more tenacious and more malleable, and thus more suitable for the finer sort of cutlery, it was subjected to a process termed 'shearing'. The process was similar to that employed by steelmakers in Styria, which is probably why the steel thus produced was sometimes called 'German' steel in England. Bars of blister steel were broken up into short lengths, four or six being then bound together into 'faggots'. After the surface had been covered with sand to prevent oxidation, the faggots were heated to a full welding heat (about 1400° C). When withdrawn from the fire, the mass was reduced to a glowing heat and then forged by a heavy hammer into a square bar.\(^1\)

If the process of welding and forging was repeated, the product was termed 'double shear', or 'Hayford steel' after its first maker, Dan Hayford of Roamley near Pontefract. This was considered the best English steel. Five different sorts were produced, distinguished by different marks. The first was called 'shear blade'. This was the softest and used for the manufacture of large cloth shears. The next sort, called 'shear-blade and star' from its mark, was somewhat harder, and was similarly used. The third called 'spur' steel was considerably harder and used for the making of penknives and fine scissors, but chiefly for engraving. The next was 'double spur', of which razors were made. At Sheffield it was also used in the manufacture of penknives. The hardest of all was 'double spur and star'. This also was used in the manufacture of razors and fine scissors, but it was particularly suitable for engraving-tools.\(^2\)

In the eighteenth century the principal production centre of shear steel was near Newcastle-upon-Tyne, at Ambrose Crowle’s steelworks. Another centre was Wortley in Yorkshire, where John Cockshutt took up the manufacture in the middle of the century, but the steel he made was not of such a high repute as Crowle's. English shear steel, in particular Crowle’s, proved to be superior to contemporary German steel produced in Styria and the Tyrol and up to then imported in large quantities into England. English cutlers who had formerly employed it in the manufacture of knife blades found it to be 'harder, rawer' and 'less manageable' than English shear steel. Only Cockshutt at Wortley employed imported German steel on account of its hardness for the manufacture of drawing-plates used for drawing steel wire.

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Steel

Even the sword blade-makers who had come from Germany, in particular from Solingen, and settled at Shotley Bridge, County Durham, did not use steel from Germany, but obtained their supply from Dan Hayford’s forge at Roamley.¹

Steel produced by cementation, whether blister or sheaf steel, was never completely uniform in texture, since some particles of silicate of slag were present even in the best of it. A steel homogeneous in composition and more free from impurities than any other steel made previously was first produced when Benjamin Huntsman invented a method of making crucible or cast steel. Huntsman, born in 1704, first established himself as a clockmaker at Doncaster where he experimented with the object of producing a more uniform steel suitable for the springs of clocks and pendulums. Between 1740 and 1742 he removed to Handsworth near Sheffield, and after many attempts and failures he finally succeeded in finding a method of producing steel in a molten state, in which it could be poured and cast like molten iron. His process is known as the crucible process. Bars of blister steel previously broken into short lengths were placed, with added fluxes, in closed crucibles of Stourbridge clay from nine to eleven inches high. They were then melted by intense heat generated in a coke furnace. The blister steel had usually been twice refined already. Sometimes ‘cuttings and scraps of shapes and other small iron wares’ were added. Of primary importance was the flux added to the charge in the crucibles, the nature of which was jealously guarded. It was first made known in a Swedish travel report of 1804, according to which the flux consisted of ‘broad leaf tree charcoal with some ashes’.²

Apart from its uniformity of composition cast steel still had positive advantages over sheer steel. The process of producing it was less complex and therefore quicker and cheaper. On the other hand, cast steel could not be welded, since it would not bear more than a red heat, otherwise it ‘runs away under the hammer like sand’.³

Production of cast steel was taken up very slowly in England before 1770. By 1787, however, eleven firms producing cast steel were established at Sheffield, the most important of which were those of Huntsman’s son and of the Walkers.⁴

CHAPTER XIX

TRANSITION FROM CHARCOAL TO COKE

In the course of the eighteenth century the British iron industry underwent a change only comparable in magnitude to that of the sixteenth, when it was transformed through the introduction of the blast furnace and the power forge.

In one respect, however, the effects were precisely opposite. Whereas the sixteenth century saw an unprecedented increase in the use of charcoal, the change of the eighteenth century resulted in the collapse of the charcoal-iron industry; and by the year 1800 charcoal as a fuel had been almost entirely superseded by coke.

The process of transition, however, was gradual. In the first half of the century the use of coke for smelting was confined to only a few furnaces, while the majority were still using charcoal. Up to about the middle of the century the charcoal-iron industry was even being extended to new areas such as Cumberland, north Lancashire, and Scotland. On the other hand, production of iron with coke which had been rendered possible by Abraham Darby's first successful attempts in 1709, was being practised only at the Darbys' ironworks at Coalbrookdale in Shropshire, and a few other furnaces, though even there coke was not yet used exclusively.

In the early days smelting with coke was confined to the production of cast-iron ware, such as pots and similar utensils, but castings still represented a small proportion of the furnace output. The principal product required was a pig iron suitable for conversion into malleable iron. In this respect production of pig iron with coke was a failure and remained so for many years. It was too brittle for conversion into bar iron. An inventory of 1718 shows that at Coalbrookdale defective pig iron had accumulated which was sold to forges in the vicinity at a low price. At the two furnaces outside Coalbrookdale which used coke for smelting in the early eighteenth century, namely Redbrook on the

\[1\] Ashton, p. 28 et seq.
Transitions from Charcoal to Coke

border of the Forest of Dean, and Bershaw in north Wales, the situation was similar. It seems that at both places the use of coke was only very limited, and that it was soon discontinued. Of the furnaces controlled by the Foley partnership in the Forest region Redbrook was the only one at which coke-smelted pigs were produced in the campaign of 1716-17, while at all the others charcoal was used for smelting. Even at Redbrook the pig iron 'made with stone coal', previously 'charked', did not exceed four tons according to the inventory, compared with 159 tons of pigs smelted with charcoal. The discontinuance of the practice in later years and the lower price of coke-pigs, which sold at £6 per ton instead of the £7 158. od. paid for charcoal pigs, suggests inferior quality.1 At Bershaw coke was first used in 1721, for the casting of cooking-pots, but there is nothing to show that it was used in the following years. In 1726, the furnace was operated first with charcoal for six months, and then blowing 'begun with coals in the evening of September 13'. The new process does not seem to have brought prosperity to Bershaw, for by 1726 the owner was in financial difficulties which compelled him to give up the lease of the ironworks a year later.2

It was not until the middle of the century that coke-smelted iron began to be more widely accepted. Up to then, it was mainly used for nails on account of its cheapness, and it was no rival to iron produced with charcoal. About 1750 coke pigs had improved in quality, so that the forgemasters of Worcestershire began to use it.3 By that time smelting with coke had begun to spread to new regions. The first coke blast furnace in the north was erected at Chester-le-Street, County Durham; it was 35 feet high. This furnace, however, was short-lived, because ore had to be imported all the way from Whitby. In Cumberland a coke furnace was built at Little Clifton in 1750. Shortly afterwards smelting with coke was introduced into south Wales and Scotland. Josiah Guest, a Shropshire man from the district of Coalbrookdale, introduced the new process at Dowlais, near Merthyr Tydfil in south Wales. From 1759-60 a coke blast furnace was being built at the Carron ironworks at Falkirk in Stirlingshire. In Scotland the transition from charcoal to mineral coal and coke was closely connected with the rise of the clayband iron industry. At the Carron ironworks the carboniferous clayband ore (carbonate of iron) was first employed in smelting which commenced on 1st January 1760. Both ore and fuel required a stronger air-blast than the leather bellows hitherto employed were able to supply, and in the early days of Carron the leather bellows were replaced by the first cast-iron blowing-cylinder, built by the celebrated English civil engineer John Smeaton.

At this date, however, not more than seventeen coke furnaces were

1 Johnson, pp. 16, 49.
2 A. Stanley Davies, 'The Early Iron Industry in North Wales', Note. Tr., vol. xxv, p. 84.
3 Ashton, pp. 35-36, 251.
in blast in the whole of Britain. Fourteen more were erected in the 1760’s and the early 1770’s, but the greatest increase took place from 1775 onwards, so that before 1790 the number of coke furnaces active in Britain had more than doubled. By 1790 only twenty-five charcoal blast furnaces were still in operation compared with eighty-one operated with coke, of which thirty-five were in the Midland counties; twenty-four in Shropshire, the original home of the coke furnace, and eleven in Staffordshire.¹

The best results of smelting with coke were not achieved until James Watt had developed his steam-engine so far that it could be substituted for the inefficient water-driven bellows hitherto used, so that it became possible to apply increased power for blowing and mechanical power for forging. The decisive year was 1775, when Watt pushed his invention from the experimental to the commercial stage. In the following year the first steam-engine to be applied to purposes other than pumping water was installed. It was installed for blasting at John Wilkinson’s furnace at Willey in Shropshire.² This event marked the beginning of a period in which the problem of fuel supply was finally solved by a general substitution of coke obtained from the abundant resources of mineral coal available in the country.

Great changes in the regional distribution of the iron industry were effected by the transition from charcoal to mineral fuel. Ironworking in regions such as the Weald of Sussex, Kent, and Surrey, which in former centuries had been main centres of iron production became uneconomic on account of the expensive charcoal on which they had to rely, although the ore they used was more abundant, and often purer than that available in many other coalfields.³

In south Wales, on the other hand, where the iron industry had almost ceased on account of the lack of wood for charcoal, a complete revival started in the late eighteenth century owing to the abundance of high-quality coal available in the great coal basin of south Wales. A series of blast furnaces was erected along a band of mountain land eighteen miles long and about a mile wide, extending from Hirwain to Blaenavon.⁴

The decline of the charcoal-iron industry in Britain and the rise of a new industry producing with coke as a fuel is reflected in the figures of production.

The evolution of the charcoal-iron industry operated by the indirect method, which prior to 1580 had been confined to the south-east of England, but in the subsequent seventy years had expanded over the

whole of the British Isles, culminated in a boom period between the end of the Spanish war in 1604 and about 1635. It was the period in which English cast-iron cannon still were in great demand on the European market and the art of casting ornamented firebacks had developed into a typically English style. The boom was brought on by an increased demand for iron both within the country and from without, in particular from Holland, which in those days attained its highest level in economic and cultural development.\textsuperscript{1} As a result larger furnaces and forges were erected in Britain and output was greater than ever before. Exact figures of the number of ironworks and of their output are not available, although there is no lack of contemporary computations, the most acceptable of which appears to be an estimate made in 1636 in the course of proceedings taken on behalf of the Crown against the Midland ironmaster Richard Foley regarding his excessive consumption of wood. Here the number of furnaces and forges operated since 1627 in England (including Wales) is given as ‘about 300’.\textsuperscript{2} Since the proportion, usual in the period concerned, was one furnace to two forges, the number of furnaces may safely be estimated at about one hundred which tallies fairly well with the available documentary evidence.\textsuperscript{3} The average annual output of pig iron was 250 tons per furnace, which makes a total output of 25,000 tons.\textsuperscript{4} If we assume that about 5\% castings were added which was the normal proportion in those days, the total output of all the furnaces in England and Wales between about 1625 and 1635 would be approximately 26,000 tons a year. At the ratio of four tons of pig iron to three of wrought or bar iron into which it was converted in the forges, the total production of bar iron would be 18,750 tons. These

\textsuperscript{1} The extent of the demand is shown in a letter directed to the Earl of Cork in 1619 in which his agent reported that London iron-merchants were buying all the iron at Bristol, since the supply of bar iron from the Sussex works was exhausted, Cork MS, vol. 10, No. 14. As a result, in subsequent years Irish iron though inferior in quality was exported in large quantities to Holland either via London or directly to Amsterdam.

\textsuperscript{2} PRO, SPD, Chas. I, vol. 319, No. 109 — S. Sturtevant in his Metallica, London, 1612, claimed on pp. 4-5 to have been credibly informed that in the whole of the British Isles 800 iron mills were in existence. This figure which was repeated by Dud Dudley, Metalum Martinis, p. 36, London, 1665, is definitely too high, in any case for England and Wales, since he ascribed 400 to Surrey and Sussex and 200 to Wales, which is far above any figures ever attained at any time, even if the bloomeries still existing in his days were included.

\textsuperscript{3} See App. V.

\textsuperscript{4} The daily output per furnace was 1\frac{1}{2} tons on the average (less in the Weald, but more in the Forest of Dean and the north, see App. IV). This makes 12\frac{1}{2} tons per week or 250 tons per furnace in a blowing period of 20 weeks a year, which was considered the minimum required to make the operation of a furnace profitable (see above p. 243). An average annual output of 250 tons per furnace, derived from documentary evidence, agrees with an estimate made by Professor J. N. Nef, J. of Political Economy, vol. xliv, p. 401 (‘well under 300 tons’), Chicago, 1936. In this calculation Scotland and Ireland are not included. In Scotland only a few isolated blast furnaces were in operation (see above p. 191), but many more in Ireland. According to a statement kindly supplied by Miss E. McCracken, Londonderry, and to be published in the 1957 issue of the Ulster Journal of Archaeology, ‘at least' 53 furnaces and forges and probably many more were in Ireland before the rebellion of 1641.
Transition from Charcoal to Coke

figures, based on a careful calculation, represent the highest annual output ever attained in the English charcoal-iron industry.

Set against the background of the preceding boom, the hundred years after the Civil War appear as a period of steady, though slow, decline. Although according to a list of 1717 the number of blast furnaces and forges went down considerably, and also the total output,¹ production per furnace increased.² This was due principally to an improvement in the shape of the inner cavity, which from about 1650 onwards was built circular, and to the better quality of the charcoal obtained from the coppices which by that time were established all over the country. Despite such improvements there was an apparent decline in total production. Cheap iron, of which large quantities were imported from Sweden, spoilt the market for English producers. For the growing manufacture of steel by the cementation process Swedish bar iron was used, since it was of superior quality. In the eighteenth century the market for English charcoal iron deteriorated still more because of importations from the American colonies and from Russia. The tide began to turn in the latter part of the century, when coke instead of charcoal began to be used increasingly. The resulting improvement is clearly shown in the following schedule.

<table>
<thead>
<tr>
<th>Year</th>
<th>total no.</th>
<th>in blast</th>
<th>fuel used</th>
<th>total</th>
<th>per furnace</th>
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<tbody>
<tr>
<td>1717</td>
<td>61</td>
<td>56</td>
<td>charcoal</td>
<td>18,490</td>
<td>330 ¹*</td>
</tr>
<tr>
<td>1720</td>
<td></td>
<td>59</td>
<td>charcoal</td>
<td>17,350</td>
<td>294 ¹†</td>
</tr>
<tr>
<td>1788</td>
<td>85</td>
<td>77</td>
<td>charcoal (24)</td>
<td>61,900</td>
<td>804 average (charcoal 546, 162; coke 907) ³‡</td>
</tr>
<tr>
<td>1796</td>
<td>121</td>
<td></td>
<td>coke (53)</td>
<td>124,897</td>
<td>1032 ³§</td>
</tr>
<tr>
<td>1805</td>
<td>236</td>
<td>177</td>
<td>coke (except a few isolated furnaces)</td>
<td>250,507</td>
<td>1,415.3 ³§</td>
</tr>
</tbody>
</table>


Around 1750 Sweden was the world's chief iron-producer, manufacturing about one-third of the total consumed throughout the world. Thereafter began the rapid growth of the British coke-using iron industry, and by the year 1850 this country was producing half the world's iron.

¹ In addition to the 61 furnaces, there were 119 forges with a total output of 13,660 tons of bar iron, Notec. Tr., vol. ix, p. 23.  ² See the above schedule.
APPENDICES
# APPENDIX

Analyses of Prehistoric,

<table>
<thead>
<tr>
<th>Character of object</th>
<th>Chain¹</th>
<th>Wheel Tyre²</th>
<th>Bloom³</th>
<th>Currency bar⁴</th>
<th>Currency bar⁴</th>
<th>Currency bar⁴</th>
<th>Currency bar⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place of origin or preservation (….)</td>
<td>East Anglia</td>
<td>Origin obscure</td>
<td>Wookey Hole, Som.</td>
<td>1st cent.</td>
<td>1st cent.</td>
<td>1st cent.</td>
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<tr>
<td>Date</td>
<td>100–50 B.C.</td>
<td>150 B.C.–A.D. 50</td>
<td>1st cent.</td>
<td>b.c.</td>
<td>b.c.</td>
<td>b.c.</td>
<td>1st cent.</td>
</tr>
<tr>
<td>Total Carbon co-combined gr. as graphite Silicon</td>
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<td>0·74–0·96</td>
<td>0·48</td>
<td>0·06</td>
<td>0·08</td>
<td>trace</td>
<td>trace</td>
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<tr>
<td>less than 0·05</td>
<td></td>
<td></td>
<td>0·61</td>
<td>0·11</td>
<td>0·02</td>
<td>0·09</td>
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<td>Manganese</td>
<td>trace</td>
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<td>nil</td>
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<tr>
<td>Sulphur</td>
<td>trace</td>
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<td>0·69</td>
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</tr>
<tr>
<td>Slag inclusions</td>
<td>considerable</td>
<td>only a few stringers</td>
<td>0·55</td>
<td></td>
<td></td>
<td>No slag detected</td>
<td></td>
</tr>
</tbody>
</table>

¹ Fox, pp. 38, 84.
² Fox, pp. 75–76.
³ By courtesy of the British Cast Iron Association, Bordesley Hall, Alvechurch, Birmingham.
Roman and Medieval Iron

<table>
<thead>
<tr>
<th>Cast-iron block</th>
<th>Nails</th>
<th>Chisel</th>
<th>Cast-iron block</th>
<th>Iron strip</th>
<th>Lynch pin</th>
<th>Iron block</th>
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<td>Hengistbury Head, Hants</td>
<td>Richborough, Kent</td>
<td>Chesterholm, Northumb., 2nd cent.</td>
<td>Wilderspool, Lancs.</td>
<td>2nd century A.D.</td>
<td>varying from 0-5</td>
<td>Corbridge, Northumb., 3rd-4th cent. A.D.</td>
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<tr>
<td>3'49 (co. 3'33, gr. 0'16)</td>
<td>0'08 0'07</td>
<td>variation from below 0'1 to 1'3 0'098</td>
<td>3'23 (co. 0'23, gr. 3'00)</td>
<td>1'05</td>
<td>trace</td>
<td>0'097</td>
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<tr>
<td>value too uncertain in consequence of slag inclusions</td>
<td>trace</td>
<td>Nil</td>
<td>Nil</td>
<td>0'403</td>
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<td>trace</td>
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<td>Nil</td>
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</tr>
<tr>
<td>considerable</td>
<td>large inclusions near the head</td>
<td>—</td>
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<td>0'380</td>
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that the last-mentioned currency bar had been made from meteoric iron because of the nickel content and the absence of slag patches. The content of nickel, however, is very low for meteoric iron (Coghlan, p. 35).

9 *Proceedings of the University of Durham Philosophical Society*, vol. ix, Part iii, pp. 141-145.
8 'Average analysis', *Jr.,* vol. 85, p. 127.

[Table continued on p. 340.]
<table>
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<tr>
<th>Character Place</th>
<th>Cast-iron block</th>
<th>Axe</th>
<th>Axe</th>
<th>Axe</th>
<th>Bloom</th>
<th>Split bloom</th>
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<tr>
<td>Date 2nd-4th cent. A.D.</td>
<td>Late 3rd and 4th cent. A.D.</td>
<td>varying from below 0.05 to more than 0.6</td>
<td>0.23</td>
<td>0.49</td>
<td>0.08</td>
<td>0.05-0.47</td>
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<tr>
<td>C 0.12</td>
<td>0.52</td>
<td>(co. 0.031, gr. 3.21)</td>
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<tr>
<td>Si</td>
<td>uncertain</td>
<td>0.5222</td>
<td>trace</td>
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<td>0.04</td>
<td>0.016</td>
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<td>Mn</td>
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<td>0.013</td>
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<tr>
<td>S</td>
<td>0.004</td>
<td>0.049</td>
<td>0.007</td>
<td>0.008</td>
<td>0.011</td>
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<td>Slag</td>
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</table>

10 Composition of the slag-free metal. The bloom contained rather a large amount of 'slag' inclusions, magnetic separation gave a value of 7-25% non-magnetic material ('slag') which does not include the corrosion product on the outside of the bloom. By courtesy of the British Cast Iron Research Association, loc. cit.

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APPENDIX II

Wood Grant for Charcoal to Fountains Abbey, 1195

Oxford, Bodleian Library, Rawlinson MS B449, fol. 150v (copy of the thirteenth century).

Willelmus de Estutuillæ1 ballivis et forestariis suis de Knaresborough et omnibus amicis suis visuris vel audituris litteras istas salutem.

Sciatis me concessisse et hac in car(ta) confr(mare) magistro fabro de Font(ains) carbonem ad ar dendum in foresta mea de Knaresburgh ubi- cumque et quantumcumque voluerit de mortuo bosco tam de stante quam de iacente et ad ducendum quocumque voluerit infra forestam meam et extra. Et ideo volo et precipio quod ipse et suis carbonem in bona pace ardeant et ducant quo voluerint sicut predictum est absque omni impedi- mento. Reddendo inde mihi per annum decem sol(idos) et tres dacras² ferrarum equorum. Hunc autem carbonem ardebit predictus faber quamdiu ipse voluerit per predictam firmam. Terminus autem huius convencionis incepit ad pascha anno ab incarnacione domini M(o)XCV10.

1 The manor of Knaresborough was granted to William de Stutevill (died in 1203) by King Henry II (i.e. before 1189), ETCs, vol. 1, p. 391.
2 In the Middle Ages a dacre of horseshoes contained twenty of such shoes.
APPENDIX III

Application of Water as Motive Power in British Ironworks, prior to 1450

Date


1346 Iron mill near Liverpool, Lancashire (term of "mOLEndinum ferri" applied), BM, Add. MS 32103, fol. 140.

Fourteenth century In the wood just across the bridge over the river Mite, west of Eskdale, Cumberland, a bloomery site associated with fourteenth-century pottery, with a leat from the river serving the bloomery (evidence supplied by Miss M. G. Fair, Eskdale, who discovered and examined the site).

1395 Bloomsmithy at Creskeld Park near Otley, Yorkshire; watercourse leading to one water wheel (unius rote). Leeds, Yorkshire Archaeological Society, Deed C. 25.

1408 Byrkeknott near Bedburn in Weardale, County Durham, forge: stone channel (watergate) and wooden spouts (spowtes) for leading water to a water wheel (rota aquatica). *English Historical Review*, vol. xiv, p. 517. London, 1899.

1418 Clayton near High Hoyland, Yorkshire: permission to erect smithies with a watercourse to smelt iron (cum cursu aque dictis fabricis ducendo pro ferro ibidem comburendo). PRO, *Duchy of Lancaster, Ministers' Accounts*, Bundle 507, No. 8230.

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Application of Water as Motive Power in British Ironworks

1428 West of Crawcrook near Ryton on Tyne, County Durham: Licence granted to Robert Kyrhous, ‘Ironbrenner’ to keep smithies going ‘at all times reasonable when water will serve him’; ‘ground reasonable for his smethichouses and watergates to the said smethies’. PRO, Durham, 3 No 37, memb. 3d.


1449 Tong smithy near Leeds, Yorkshire, diversion of a watercourse and erection of pools (stagna) granted. Farnley Deed No. 1 (in possession of Mr. Armitage, Farnley Hall).
APPENDIX IV

Output Figures

*Chart of Production* between 1330 and 1750 (on a 24 hours basis).

(A) bloomery; (B) general development of blast furnace production; (C) in Sussex.
## Output Figures

### Bloomery

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<th>Year</th>
<th>Place</th>
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<th>Evidence</th>
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<tr>
<td></td>
<td></td>
<td>per annum</td>
<td>per 24 hrs.</td>
</tr>
<tr>
<td>1339-54</td>
<td>Kent and Northumberland</td>
<td>2 t. 10½ c.</td>
<td>32½ lb.</td>
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<td>1408-09</td>
<td>Byrkeknott (Durham)</td>
<td>25 t. 2 c.</td>
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<tr>
<td>1507</td>
<td>Treeton, south-east of Sheffield, (Yorks.)</td>
<td>41 t. 12 c.</td>
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</tr>
<tr>
<td>1531</td>
<td>Llantrissant (Glamorgan)</td>
<td>45 t (estimate)</td>
<td>2½ c.</td>
</tr>
<tr>
<td>1541</td>
<td>Rievaulx (Yorks.)</td>
<td>18 t. (estimate)</td>
<td>appr. 2 c.</td>
</tr>
<tr>
<td>1544</td>
<td>Goodrich (Herefordshire)</td>
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<td>1567-68</td>
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<td>32 t. 15 c.</td>
<td>appr. 2½ c.</td>
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<td>appr. [252 d.]</td>
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<td>1576</td>
<td>Farnley Smithy, nr. Leeds (Yorks.)</td>
<td>27 t. 12 c.</td>
<td>2 c.</td>
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<td>1582</td>
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<td>[276 d.]</td>
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<td>1584</td>
<td>Emley (Yorks.)</td>
<td>18 t. 1 c.</td>
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<td>27 t. 6 c.</td>
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<td>[252 d.]</td>
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</tr>
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<td>Osspring (Yorks.)</td>
<td>6 t. 14½ c.</td>
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<td>2 c. 7½ lb.</td>
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Output Figures

1330 and 1598

[...] time of blowing, d=days, w=weeks

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BLAST FURNACE

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<td>1594</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1598</td>
</tr>
</tbody>
</table>

Panningridge (Sussex)

287 t. 16 c. 35½ lb. Pe., No. 377. 1546
315 d. 15 c. 24 lb. 1558
171 t. 5 c. 15 c. 58½ lb. 1559
228 d. appr. 16 c. 1560
163 t. 193 t. 10 c. Pe., No. 378. 1562
[210 d.] [178 d.] 16 c. 50 lb. 1567-68
61 t. 7½ c. 1 t. 2 c. 7½ lb. Pe., No. 387. 1576
[75 d.] 110 t. 1582
Taff Furnace, nr. Cardiff

205 t. 5 c. 1 t. 1 c. 7½ lb. 1583
[186 d.] 200 t. 1585
200 t. 1587

Pontymoel (Mon.)

200 t. PRO, Special 1588
200 t. Commissions, No. 1518.

Canckwood (Staffs.)

1 t. PRO, Exchequer KR 1589
21 w. Accounts, 546/16, vol. m. Be., No. 878.

Canckwood (Staffs.)

1 t. (estimate) BM, Landal. MS. 56, 1590
1 t. No. 37. 1591

Rievaulx (Yorks.)

98 t. 11 c. 14 lb. Middleton Papers. 1592
[21 w.] 19 c. 18½ lb. Be., Nos. 529-530. 1593

Rievaulx (Yorks.)

191 t. 7 c. 28 lb. (winter) 1594
[26½ w.] 1 t. 3 c. 1598

Oakamoor (Staffs.)

160 t. 160 t. Middleton Papers. 1599
97 t. 19 c. 1598
## Output Figures

### Output of blast furnaces between 1603 and 1686

<table>
<thead>
<tr>
<th>Year</th>
<th>Place</th>
<th>Time of blowing</th>
<th>Total output</th>
<th>per 24 hrs.</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1603</td>
<td>Rievaulx (Yorks.)</td>
<td>19 w. 4 d.</td>
<td>239 t. 17. c. 91 lb</td>
<td>1 t. 13. c.</td>
<td>Be., No. 588.</td>
</tr>
<tr>
<td>1605</td>
<td>Oakamoor (Stafs.)</td>
<td>18 w. 4 d.</td>
<td>233 t. 12 c. 24 lb</td>
<td>approx. 1 t. 16 c.</td>
<td>Be., No. 881.</td>
</tr>
<tr>
<td>1610-11</td>
<td></td>
<td>21 w. 5 d.</td>
<td>276 t. 6 c. 70 lb</td>
<td>approx. 1 t. 16 c.</td>
<td><em>Middleton Papers.</em></td>
</tr>
<tr>
<td>1613</td>
<td>Rievaulx (Yorks.)</td>
<td>8 w. 3 d.</td>
<td>124 t. 4 c.</td>
<td>2 t. 2 c. 3 lb.</td>
<td>Be., Letter of 25th May 1611.</td>
</tr>
<tr>
<td>1615</td>
<td></td>
<td>17 w. 1 d.</td>
<td>243 t. 14 c.</td>
<td>2 t. 69 lb.</td>
<td>Be., No. 459.</td>
</tr>
<tr>
<td>1616-17</td>
<td></td>
<td>20 w. 4 d.</td>
<td>286 t. 8 c. 70 lb</td>
<td>approx. 2 t.</td>
<td>Be., No. 532.</td>
</tr>
<tr>
<td>1622-23</td>
<td></td>
<td>17 w. 6 d.</td>
<td>247 t. 2 c. 84 lb</td>
<td>1 t. 17. c.</td>
<td>Be., No. 534.</td>
</tr>
<tr>
<td>1624</td>
<td>Cannop (Forest of Dean)</td>
<td>approx 20 w.</td>
<td>284 t. 17 c. 68 lb</td>
<td>approx. 1 t.</td>
<td>Be., No. 533.</td>
</tr>
<tr>
<td>1621-25</td>
<td></td>
<td></td>
<td>253 t.</td>
<td>164 c. (average)</td>
<td>Be., No. 536.</td>
</tr>
<tr>
<td>1632-33</td>
<td>Waldron (Sussex)</td>
<td>20 w. 26-27 w.</td>
<td>720 t.</td>
<td>approx. 2 t. 2 c.</td>
<td>BM, Add. MS 33-154.</td>
</tr>
<tr>
<td>1634-35</td>
<td></td>
<td>about 30 w.</td>
<td></td>
<td>1 t. 6 c. 84 lb.</td>
<td>Be., No. 537-539.</td>
</tr>
<tr>
<td>1636-37</td>
<td>Rodmore (Forest of Dean)</td>
<td>49 w. as a minimum</td>
<td></td>
<td>1 t. 7 c. 20 lb.</td>
<td>CRO, Ipswich, North Family MSS</td>
</tr>
<tr>
<td>1638</td>
<td>Rievaulx (Yorks.)</td>
<td>25 w.</td>
<td>417 t.</td>
<td>1 t. 4.4 c.</td>
<td><em>Jo., vol. 173, p. 162.</em></td>
</tr>
<tr>
<td>1641</td>
<td></td>
<td>22 w. 3 d.</td>
<td>242 t.</td>
<td>15 c. per week i.e. 2 t. 3 c. per day</td>
<td>Estimate, BM, Harl. MS 6989.</td>
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<tr>
<td>1649</td>
<td></td>
<td>Nov. to 13th May</td>
<td>213 t.</td>
<td>2 t. 17 c. 35 lb.</td>
<td>Journal of the Derbyshire Archaeological &amp; Natural History Soc., vol. x, p. 34.</td>
</tr>
<tr>
<td>1657</td>
<td>Parkend (Forest of Dean)</td>
<td>26 w. 11 w.</td>
<td>207 t.</td>
<td>2 t. 9 c. 73 lb.</td>
<td><em>EcHR, second series, vol. iv, p. 338.</em></td>
</tr>
<tr>
<td>1658-59</td>
<td></td>
<td>16 w. 6 d.</td>
<td>419 t. 17 c. 28 lb</td>
<td>3 t. 1 c. 191 lb.</td>
<td>Ray, p. 135.</td>
</tr>
<tr>
<td>1659-60</td>
<td>Foxbrook (Derbyshire)</td>
<td></td>
<td>230 t. 16 c. 14 lb</td>
<td>3 t. 14 c. 32 lb.</td>
<td>Plot, pp. 158, 164.</td>
</tr>
<tr>
<td>1662</td>
<td></td>
<td></td>
<td></td>
<td>2 t. 103 lb.</td>
<td></td>
</tr>
<tr>
<td>1662-63</td>
<td>Tintern (Montmouthshire)</td>
<td>32 w. 1 d.</td>
<td>725 t.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1672-73</td>
<td></td>
<td>45 w. 4 d.</td>
<td>792 t.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1675-76</td>
<td></td>
<td>21 w. 4 d.</td>
<td>462 t.</td>
<td></td>
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<tr>
<td>1674</td>
<td>Sussex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1686</td>
<td>Staffordshire &amp; Worcestershire</td>
<td>62 w. 61 w.</td>
<td>1142 t.</td>
<td>2 t. 12 c. 70 lb.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1034 t.</td>
<td>2 t. 8 c. 29 lb.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8 t. per founday i.e. 1 t. 6 c. 74 lb</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2-3 t.</td>
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Output of blast furnaces between
A dash indicates absence of information. Output per 24 hours in parentheses:

<table>
<thead>
<tr>
<th>Year</th>
<th>Blakeney</th>
<th>Bishopsg</th>
<th>Elmbridge</th>
<th>Gunn Mill</th>
</tr>
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<tbody>
<tr>
<td>1688-89</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1689-90</td>
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<tr>
<td>1690-91</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1691-92</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1692-93</td>
<td>273 (2 t. 4 c. 43 lb.)</td>
<td>739</td>
<td>597 (2 t. 14 c. 30 lb.)</td>
<td></td>
</tr>
<tr>
<td>1693-94</td>
<td>925</td>
<td>488</td>
<td>541 (2 t. 6 c. 94 lb.)</td>
<td></td>
</tr>
<tr>
<td>1694-95</td>
<td>810</td>
<td>753</td>
<td>689</td>
<td></td>
</tr>
<tr>
<td>1695-96</td>
<td>1047</td>
<td>537</td>
<td>785</td>
<td></td>
</tr>
<tr>
<td>1696-97</td>
<td>794 (2 t. 15 c.)</td>
<td>777</td>
<td>694 (2 t. 14 c. 48 lb.)</td>
<td></td>
</tr>
<tr>
<td>1697-98</td>
<td>697 (2 t. 16 c. 23 lb.)</td>
<td>684</td>
<td>790 (2 t. 14 c. 96 lb.)</td>
<td></td>
</tr>
<tr>
<td>1698-99</td>
<td>995 (2 t. 10 c. 85 lb.)</td>
<td>656</td>
<td>346 (2 t. 7 c. 81 lb.)</td>
<td></td>
</tr>
<tr>
<td>1699-1700</td>
<td>725 (2 t. 56 lb.)</td>
<td>825</td>
<td>736</td>
<td></td>
</tr>
<tr>
<td>1700-01</td>
<td>725</td>
<td>825</td>
<td>736</td>
<td></td>
</tr>
<tr>
<td>1701-02</td>
<td>508 (3 t. 5 c. 109 lb.)</td>
<td>522</td>
<td>595</td>
<td></td>
</tr>
<tr>
<td>1702-03</td>
<td>922 (2 t. 18 c. 9 lb.)</td>
<td>674</td>
<td>673</td>
<td></td>
</tr>
<tr>
<td>1703-04</td>
<td>574 (2 t. 16 c. 30 lb.)</td>
<td>575</td>
<td>755</td>
<td></td>
</tr>
<tr>
<td>1704-05</td>
<td>917</td>
<td>810</td>
<td>552</td>
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<tr>
<td>1705-06</td>
<td>441</td>
<td>740</td>
<td>390</td>
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<td>1706-07</td>
<td></td>
<td></td>
<td></td>
<td>779</td>
</tr>
<tr>
<td>1707-08</td>
<td>866</td>
<td></td>
<td>712</td>
<td>Nil</td>
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<td>1708-09</td>
<td>553</td>
<td>Nil</td>
<td>495</td>
<td>Nil</td>
</tr>
<tr>
<td>1709-10</td>
<td>869</td>
<td>726</td>
<td>349</td>
<td>Nil</td>
</tr>
<tr>
<td>1710-11</td>
<td>628</td>
<td>532</td>
<td>336</td>
<td>562</td>
</tr>
<tr>
<td>1711-12</td>
<td>1066</td>
<td>489</td>
<td>592</td>
<td>153 (2 t. 3 c. 80 lb.)</td>
</tr>
<tr>
<td>1712-13</td>
<td>435</td>
<td>526</td>
<td>275</td>
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<tr>
<td>1713-14</td>
<td>625</td>
<td>409</td>
<td>195</td>
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</tr>
<tr>
<td>1714-15</td>
<td>614</td>
<td>150</td>
<td>683</td>
<td></td>
</tr>
<tr>
<td>1715-16</td>
<td></td>
<td>535</td>
<td>253</td>
<td></td>
</tr>
<tr>
<td>1716-17</td>
<td></td>
<td>201</td>
<td>568</td>
<td></td>
</tr>
<tr>
<td>1717-18</td>
<td>600</td>
<td>600</td>
<td>523½</td>
<td>200</td>
</tr>
<tr>
<td>1718</td>
<td></td>
<td></td>
<td>523½</td>
<td>620 t. 6 c. (2 t. 1 c.)</td>
</tr>
</tbody>
</table>

1 Figures of annual output are taken mainly from the accounts of the Foley partnerships, published by R. L. C. Johnson, EtHR., second series, vol. iv, p. 338. Otherwise evidence is mentioned in the subsequent footnotes.
3 PRO, Audit Office, Accounts various, No. 1243.
4 CRO, Gloucester, D421/E9.
1688 and 1781 (in tons)\(^4\)

figures can only be derived if evidence of the time of blowing is available.

<table>
<thead>
<tr>
<th>VICINITY</th>
<th>LANCASHIRE</th>
<th>SUSSEX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Redbrook</td>
<td>St. Weonards</td>
</tr>
<tr>
<td></td>
<td>—</td>
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</tr>
<tr>
<td>616 l. 6(\frac{1}{3}) c. (21.8 c.)(^4)</td>
<td>—</td>
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<tr>
<td>158</td>
<td>—</td>
<td>239</td>
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<td>973</td>
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<tr>
<td>531</td>
<td>—</td>
<td>686</td>
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<td>168</td>
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<tr>
<td>704</td>
<td>723</td>
<td>—</td>
</tr>
<tr>
<td>678</td>
<td>519(^\frac{1}{3}) (2 l. 2 c. 46 lb.)</td>
<td>—</td>
</tr>
<tr>
<td>450</td>
<td>694(^\frac{1}{3}) (2 l. 3 c. 15 lb.)</td>
<td>—</td>
</tr>
<tr>
<td>862</td>
<td>860 (2 l. 2 c. 65 lb.)</td>
<td>—</td>
</tr>
<tr>
<td>775</td>
<td>733</td>
<td>—</td>
</tr>
<tr>
<td>899</td>
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</tr>
<tr>
<td>693</td>
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<tr>
<td>513</td>
<td>519</td>
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</tr>
<tr>
<td>600</td>
<td>300(^6)</td>
<td>300</td>
</tr>
<tr>
<td>333(^4) (3 l. 4 c.)(^4)</td>
<td>212(^4)</td>
<td>—</td>
</tr>
</tbody>
</table>

\(^6\) The estimate of 900 tons is supplied by the list of 1717. In the Audit Office accounts (cf. note 3) only one campaign from 29th September-25th December 1717 is mentioned (output 199 tons 3\(\frac{1}{2}\) cwts. 26 lb., i.e. 2 tons 5\(\frac{1}{2}\) cwts. per 24 hours); in 1718 there were two campaigns (10\(\frac{1}{2}\) and 4 weeks, with a daily output of 2 tons 4 cwts. and 1 ton 13 cwts. respectively).

\(^7\) Barrow-in-Furness, Public Library, MSS Z186 and Z188.

\(^7\) From Pelham Accounts, BM, MS 33156.
### Output of blast furnaces between 1688 and 1718 (in tons)

A dash indicates absence of information. Output per 24 hours in parentheses; figures can only be derived if evidence of the time of blowing is available.

#### MIDLANDS AND CHESHIRE

<table>
<thead>
<tr>
<th>Year</th>
<th>Grunge</th>
<th>Hales</th>
<th>Lawton</th>
<th>Meareath</th>
<th>Staveley</th>
<th>Vale Royal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1688-89</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>502</td>
<td></td>
</tr>
<tr>
<td>1689-90</td>
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<td></td>
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<td></td>
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<tr>
<td>1690-91</td>
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<tr>
<td>1691-92</td>
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</tr>
<tr>
<td>1692-93</td>
<td>130</td>
<td>210</td>
<td></td>
<td>769 (2 t. 16 c. 37 lb.)</td>
<td></td>
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</tr>
<tr>
<td>1693-94</td>
<td>8864</td>
<td></td>
<td></td>
<td>1098 (2 t. 17 c. 71 lb.)</td>
<td></td>
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</tr>
<tr>
<td>1694-95</td>
<td>Nil</td>
<td></td>
<td></td>
<td>315 (2 t. 4 c. 76 lb.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1695-96</td>
<td>512</td>
<td></td>
<td></td>
<td>846 (2 t. 11 c. 65 lb.)</td>
<td>450</td>
<td>155</td>
</tr>
<tr>
<td>1696-97</td>
<td>152</td>
<td>627</td>
<td>644</td>
<td>250</td>
<td>481</td>
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<td>962</td>
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<td>1703-04</td>
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<td>770</td>
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<td>578</td>
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<td>642</td>
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<td>647</td>
<td>733</td>
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1 Figures of annual output are taken mainly from the accounts of the Foley partnerships, published by B. L. C. Johnson, *EcHR*, second series, vol. iv, p. 338. Otherwise evidence is mentioned in the subsequent footnotes.

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Output Figures

After 1720 evidence in respect of furnace output in the Forest of Dean area is scanty. Between 1725 and 1750, Elmbridge had an average output of 409 tons (in seven single years, extremes 119 and 546 tons), Redbrook 404½ tons (in 6 years, extremes 28 and 478 tons).¹ In south Yorkshire the output was apparently lower. In the 18 years of 1720–37, at Bank furnace average output was 378½ tons (extremes 207 and 503 tons), at Barnby approx. 296½ tons (extremes 253 and 536 tons).² Chapeltown, near Sheffield, produced 352 tons 6 cwt. in 1740–41 (approx. 2 tons per 24 hours).³ In the Midlands output was comparatively high towards the middle of the century. Charlecott furnace, Shropshire, had an average output of approx. 493½ tons in 17 years between 1732 and 1750 (extremes 33 and 763 tons). The average output of Brine-wood was still higher with 590 tons 11½ cwt. in 8 years between 1737 and 1751 (extremes 123 and 911½ tons).⁴ The average output of Aston furnace, Birmingham, in 10 years of blowing between 1751 and 1761 was 899 tons 4 cwt. (extremes 552 and 1027 tons), that of Hales, south of Dudley, between 1751 and 1763 was 450 tons (extremes 79 and 821 tons).⁵

² *Nev. Tr.*, xix, pp. 68–69.
³ *Nev. Tr.*, xxiv, p. 118 — In Sussex, daily output was 1 ton 3 cwt. in 1736 from Sussex ore, but 1 tons 15½ cwt. from Lancashire haematite, *Sussex AC*, vol. 67, p. 31. Heathfield furnace produced 316 tons 8½ cwt. in 1727, Straker, p. 375 — Dolgyn furnace, Merionethshire, produced 446 tons in 1719 in 36½ weeks which works out at 1 ton 15 cwt. per 24 hours, *Nev. Tr.*, vol. xxv, p. 86.
⁴ Kidderminster, Public Library, MSS 244 and 245.
⁵ Ibid, MSS 142–152.
# APPENDIX V

Charcoal Blast-furnaces in England and Wales

- $\Delta$ = erected
- $\Delta\Delta$ = re-erected
- $\Delta\Delta\Delta$ = closed down
- a. = ante
- c. = circa
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### Charcoal Blast-furnaces in England and Wales

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**Charcoal Blast-furnaces in England and Wales**

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**NORTH WALES**

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Charcoal Blast-furnaces in England and Wales

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365
BLAST-FURNACES IN ALPHABETICAL ORDER
(WITH EVIDENCE)

(List of 1717: *Neue. Tr.*, vol. ix, pp. 21–23; list of May 1790: Scrivenor, 1841, pp. 360–361.)

Aber-canaid, see Pontyryn.

Abercarn, Monmouthshire. Furnace erected on a tributary of the river Ebbw, probably in 1576, by Edmund Roberts who in that year was granted mineral rights and woods in the district. CRO, Newport, JCH, 1580. Roberts died in 1579, NLW, Bute Muniments B, Box 126. Furnace used before his death for casting guns. E. G. Jones, *Exchequer Proceedings (Equity) concerning Wales*, p. 257, Cardiff, 1939. From 1580 to 1597 and, probably, until his death in 1608, it was in the possession of Richard Hanbury, BM, Court Books of the Mineral and Battery Works, vol. 1, fol. 104; Add. MS 12509; PRO: Exchequer, Special Commissions, No. 1518, Depository by Commission, 39 Eliz., Hilary 23, Bills and Answers, Bundle 19, No. 24. A. A. Locke, *The Hanbury Family*, vol. 1, p. 141, London, 1916. — The site may have been on the left bank of the rivulet, since land there called Graig Ddu was held by Richard Hanbury in 1594, Rental NLW, Bute Muniments Box 126, Parcel V.

Ashburnham or Dallington furnace, par. of Ashburnham (formerly Dallington)— Penshurst, Sussex, erected between 1549 and 1554 (not mentioned in the portmen's complaint of 1548, but referred to in 1554 as 'Mr. Ashburnhams fornes'). The furnace was definitely in operation in 1556 at which date Mr. Ashburnham's 'founder' was mentioned; it is referred to in a document of 1563 in which the death of John Ashburnham is recorded. In 1565 about 10 tons and in 1566 63 tons of sow iron were delivered to Robertsbridge. The furnace was the last worked in Sussex, and closed down probably in 1811. In accounts preserved at Ashburnham, pig iron in stock is last referred to in 1812, the forge in 1827. Pe., Nos. 378 and 382; Straker, pp. 364–377.

Ashurst, Kent. A furnace situated on the Medway is mentioned in 1574 and 1588. From 1591 it was probably operated by the gunfounder Thomas Browne who still worked it in 1610. Straker, p. 231.

Aston furnace, Warwickshire, on Hockley Brook near the present site of Aston Hall in Birmingham. First evidence is of 1615, R. A. Pelham, in *Birmingham and its regional setting*, p. 149, London, 1950. It was worked by Richard Foley in 1633 (ore from Walsall) and 1636, PRO, *Chancery Proceedings*, Chas. I, F15/12, and SPD, Chas. I, vol. 327, No. 42. The furnace was closed down finally in 1783, Lewis, Knights, p. 25.

Backbarrow, on the river Leven, Lancashire. Furnace built in 1711–12, forge in 1714. The furnace was rebuilt in 1770, operated as a charcoal furnace until 1920–21 when a change over to coke took place. F. Barnes, *Barrow and District*, pp. 84, 108, Barrow-in-Furness, 1951; Fell, pp. 208–209.

Charcoal Blast-furnaces in England and Wales

_Barden_ furnace, north of Speldhurst, Kent. Originally there appears to have been a forge only; there are two references to 'Rychard Lammye at Barden, the hammerman' in the Parish Registers of Ashburnham, in 1599 and 1602 respectively. The forge was probably supplied with pig iron from the furnaces in the vicinity of Tonbridge. A furnace, first mentioned in 1653, was in use in 1683, CRO, Maidstone, U 458, T 2/1. It is in the list of 1717, but was described as 'entirely down' in 1787. Straker, p. 219.


_Barlow_, north-west of Chesterfield, Derbyshire. Furnace erected in 1605, _VCH, Derby_, vol. ii, p. 359. The furnace was still operated in 1693 when a lease was granted by the proprietor John Earl of Clare to John Jennens of Erdington Hall, near Birmingham, for 11 years, CRO, Nottingham, DDP 43/76.

_Barnby_, parish of Cawthorne, north-west of Barnsley, West Riding of Yorkshire. Furnace erected about 1650, and worked by the Spencer group of iron masters until 1750, A. Raistrick, _Newc. Tr._, vol. xix, pp. 53, 68–69, 78.


_Battle Park_, parish of Battle, furnace and forge. 'Divers' works at Battle operated by Wykes, Jefferys and others are referred to in 1574. Richard Wekes or Wykes of Battle sold pig iron to Robertsbridge from 1566 to 1573 from his 'newe furnace' which was probably Battle Park. The ironworks are mentioned last in 1652. Pe., No. 378; Straker, p. 350.

_Beckley_ furnace, formerly Conster, parishes of Brede and Beckley, Sussex. Furnace and forge were operating in 1653 according to accounts of 1653–58, Hove, Dunn Collection, Box L, 806. The forge was ruined by 1664. The furnace is still referred to as blowing in 1717, 1741 and 1744. It was last mentioned in 1787 but not working. Straker, p. 348.

_Bedgebury_, parish of Cranbrook, Kent. The furnace is referred to first in 1574, Straker, p. 282. In 1637 it was stated by the inhabitants of Cranbrook, that for casting guns and shot John Browne 'continueth the usage of one ancient furnace in the outbounds of the said parish where he had an old lease and not yet expired', PRO, SPD, Chas. I, vol. 363, Nos. 55 and 56; see also Straker, p. 126. The furnace was discontinued before 1664, but then repaired and stocked 'upon account of the warre', Straker, p. 282. It is not mentioned in the list of 1717.

_Bedwellty_, in Sirhowy Valley, Monmouthshire. Only reference to ironworks is of 1597 at which date they were in possession of John Challoner, haberdasher in London, and Thomas Moore, ironmonger at Bristol, PRO, _Exchequer Depositions by Commission_, 39 Eliz., Hilary 23.

_Beech_ furnace, Netherfield, now parish of Battle, Sussex, with a forge at Mountfield. Pig iron was bought for Robertsbridge forge from 1566 to 1570 from Richard Wekes or Wykes of Battle. The locality from which it was obtained was Netherfield situated between Beech furnace and Mountfield.
Charcoal Blast-furnaces in England and Wales

forge. The forge which was held by Wykes in 1574 and 1588, is mentioned as an 'iron hammer' as early as 1548. The furnace was owned by Thomas Haye of Hastings in 1574, and subsequently by his descendants until 1758, Pe., No. 378; Straker, pp. 114, 325–326.


Bishopwood, east of Goodrich, on the left bank of the river Wye, Herefordshire. A furnace is first mentioned in 1628 but without the name of the occupier, PRO, Exchequer Special Commissions, No. 5304. In 1639 the furnace produced 'great quantities' of castings, SPD, Chas. I, vol. 429, No. 94, and is mentioned in 1680. It was operated (with interruptions) from 1692–1751, B. L. C. Johnson, EcHR, second series, vol. iv, p. 338. S. Shaw (A Tour to the West of England, p. 195, London, 1789) visited the ironworks in 1788. The furnace is mentioned amongst the English charcoal furnaces in 1790, Scrivenor, 1841, p. 361. In 1805 it is referred to as being worked with Lancashire ore and 'ancient scoræa' which were stamped with powerful engines, E. Wedlake and J. Britton, The Beauties of England and Wales, vol. vi, p. 527; London, 1805. See also Rh. Jenkins, Neve. Tr., vol. vi (1925–26), pp. 55, 56, 58, 62.

Blackfold, parish of Cuckfield, Sussex. Furnace operated from 1574 to 1588; it was situated in Balcombe Forest, 1½ miles from its forge called Holmsted hammer which ceased working between 1653 and 1664. Straker, pp. 404–406.


Bough Beech, parish of Hever, Kent. A furnace is first mentioned in 1589 when it was sold to Thomas Browne, forgemaster of Chiddingstone, in Kent, by Thomas Willoughby. By 1629 the furnace had ceased working, as at this date the land on which it stood was described as 'now known by the common and general name of the furnace farm late'. Jo., vol. 161 (1948), p. 245; Straker, p. 218.

Bouldon, or Bowden furnace on the Cleec Brook, near Ludlow, Shropshire, was ordered in 1644 to supply a gun for the defence of Ludlow. It was active in 1670, 1696 and 1725, and is still mentioned in the list of charcoal blast furnaces of 1790. VCH, Shropshire, vol. 1, p. 473.

Brecon furnace on the Hondu brook, about a mile distant from the town of Brecon, in Breconshire, erected in 1720, probably fell into disuse in 1760. The forge was at Pipton, near Glasbury. — J. Lloyd, The early history of the old South Wales iron works (1760 to 1840), pp. 1–10, London, 1906.

Brede or Sackville furnace, parish of Udimore, Sussex. Furnace apparently erected in 1578. In the early seventeenth century the furnace passed into the possession of the Sackvilles, and was worked by Richard Lenard commemorated by the well-known fireback of 1636. In 1644 it was operated by Peter
Charcoal Blast-furnaces in England and Wales

Farnden, and from 1659 onwards by him in partnership with Samuel Gott of Battle. The furnace is mentioned in the list of 1717, but ceased working in 1766, when it was converted into a powder mill. Hove, Dunn Collection, Box L, 817 and 844. — Straker, pp. 341–344.

Brenchley, see Horsham.

Bretton, 4 miles south-west of Wakefield, West Riding of Yorkshire. Furnace worked by the Spencer partnerships from 1690 to 1750, A. Raistrick, Newc. Tr., vol. xix, pp. 54, 78.

Briggwood, west of Ludlow, Shropshire. Furnace and forge on the river Teame, erected by the Earl of Essex before 1601, PRO, Exchequer Special Commissions, No. 3874. The furnace was taken over by Richard Knight in 1698; it ceased working in 1814 or 1815. Rh. Jenkins, Newc. Tr., vol. xvii, pp. 182–184.

Broadhurst, parishes of Heathfield and Burwash, Sussex. The furnace was quite near Hawksden forge, parish of Mayfield, belonging to Thomas Morley of Glynde who died in 1558 possessed of a furnace and forge. There is no further record of the furnace, but the forge still appears on Budgen's map of 1724. Straker, pp. 287, 294–295.

Brockweir, furnace on a tributary of the river Wye, Gloucestershire. The first evidence is of 1635 at which date the furnace belonged to Sir Richard Cachmay. Rh. Jenkins, Newc. Tr., vol. vi, pp. 51, 62. It was operated in 1649, CRO, Ipswich, North Family MSS; it is mentioned in 1680, Hart, p. 103.

Buckholt, parish of Bexhill, Sussex. Furnace and forge mentioned in 1574, but the furnace was operated as early as 1565, in which year pig iron was bought for the forge at Robertsbridge from Bartholomew Jeffrey, who held the furnace until his death in 1575, Pe., 378(15), PRO, Court of Request, Proceedings, Bundle 84, No. 37. The furnace apparently ceased working shortly after 1664 at which date the ironworks is referred to as 'laid aside, only sometimes used'. Straker, pp. 356–357.

Bungehurst, parish of Heathfield, Sussex. No record of the furnace which was probably worked by the Baker family for some time during the seventeenth century. Straker, p. 287.

Burningsfold, furnace and forge, parish of Dunsfold, Surrey. The forge is mentioned first in 1567 (see Ifield); there is no definite evidence of the furnace before 1595. Both were still operated in 1656, but they were not mentioned in the list of ironworks in 1664. VCH, Surrey, vol. ii, p. 273; Straker, pp. 422–423.

Buxted, see Oldlands.

Caerphilly furnace, west of the town, in the parish of Eglwyselan. Erected in 1680, NLW, Tredegar Collection, No. 871; see also J. H. Wade, Glamorganshire, pp. 80–81, Cambridge, 1914, and E. L. Chappell, Historic Melting-grith, p. 23, Cardiff, 1940. The furnace produced pig iron preferentially for the two forges at Machen in the eighteenth century, Tredegar Collection, passim. It is mentioned in the lists of 1717 and 1790.
Charcoal Blast-furnaces in England and Wales

Cannock Chase (or Canockwood), Staffordshire, two furnaces one of which was north of Hednesford and west of the road to Rugeley, the other at Teddesley, with two forges and a third at Bromley. The last-mentioned was erected about 1561, PRO, Exchequer Special Commissions, No. 2098. Probably, at this date one of the furnaces and a forge in Cancockwood were erected by Lord William Paget who on the 16th January 1560 had obtained a licence to cut wood 'for making of iron' principally in Cannock Wood and Rugeley. Cal. of the Patent Rolls, Elizabeth, vol. 1, p. 326, London, 1936. At his death in 1563 three ironworks are referred to as being in his possession, PRO, Inquisitions post mortem, vol. 137, No. 47. From 1583 to 1589 two furnaces and two forges were operated for the Crown, and at the latter date they were leased to Fulco Grevill, but restored to the Pagets in 1597, Wm. Salt Library, Stafford, D 1734. The two furnaces and two forges in Cancockwood are still referred to in a revaluation of the property in the years of 1609 and 1610, PRO, Exchequer Special Commissions, No. 4533. 'Ironworks in Cancockwood' (not specified) and Bromley forge, owned by Wm. Lord Paget, were leased to Walter Chetwind of Rugeley in 1636-37, Wm. Salt Library, D 1734. In the list of 1717 only the forges in Cannock Chase and at Bromley are mentioned.

Cannop, on the Cannop Brook between Cinderford and Coleford, Forest of Dean, Gloucestershire. Furnace erected by Wm. Herbert, Earl of Pembroke, in 1612, destroyed in the Civil War, in 1644. See Parkend furnace.

Chappel, parish of Ecclesfield, north of Sheffield, West Riding of Yorkshire. Furnace first referred to in a rental of 1626, Bo., MS Selden, supra 166, p. 38. It was demised to Lionel Copley in 1666, together with forges at Rotherham and Attercliffe, Rotherham, Public Library, SC 16326. In the years of 1729 to 1763 it was operated by the Spencer partnerships, Raistrick, Newc. Tr., vol. xix, p. 78.

Charlott, near Cleobury North, Shropshire. Worked by the Childes of Kinlet in the seventeenth century and later, probably from 1670 to 1730. The furnace was finally shut down in 1777. VCH, Shropshire, vol. 1, p. 472; Lewis, Knights, pp. 4, 9; Johnson, p. 72 (referring to 1720).

Chiddingly, see Stream furnace.

Chingley or Shingley Furnace, parish of Goudhurst, Kent. The furnace is first referred to in November 1565 at which date plates were carried to Robertsbridge for the steelmakers, Pe., No. 384. The furnace belonged to Christopher Darell of Surrey, and was worked by Thomas Dyke of Horsmonden, Kent, together with Derondale (now Dundle) forge in 1572, CRO, Lewes, Dyke-Hutton Collection, and again in 1574, Straker, pp. 267, 276. In 1579, the furnace was demised to Thomas Dyke for 41 years. In 1597 the lease was made over to Richard Ballard of Wadhurst, Sussex, and his sons Thomas and Richard, for the remainder of the 41 years, i.e. until 1620.

Chittingly, parish of West Hoathly, Sussex, furnace first referred to in 1546 at which date pig iron was delivered to the forge at Sheffield, Sussex; closed down before 1588. Straker, p. 408.
Charcoal Blast-furnaces in England and Wales

Cleator, Cumberland. Richard Patrickson who owned iron mines in the parish of Egremont, smelted ores from Cumberland and Westmorland at Cleator. The only dates available are 1694 and 1696. Judging by the remains still standing in 1881, the furnace was a large one, the timp arch having a span of 10 feet at its widest side. It strongly indicates that the furnace was a blast furnace. The enterprise was short-lived and does not seem to have been successful, since the owner was in financial difficulties when he died in 1706. Tr. Cumberland and Westmorland Antiquarian and Archaeological Society, vol. v, pp. 9, 17, 165, 168, Kendal, 1881.

Cleobury Mortimer, Shropshire. Ironworks were erected by Robert Dudley, Earl of Leicester, after 1563 in which year manor and park of Cl. M. were granted to him. In a detailed survey of the same year no ironworks are mentioned, Longleat, Dudley Papers, vol. xvi. Although the first lease of the ironworks at Cleoburie by which they were demised to John Weston bears the date of 23rd June 1576, one of the forges situated at Rowley had been demised to Stephen Hadnall on 20th October 1571, which suggests that the ironworks including furnaces already existed at this date, ibid., vols. iii and xx. In a survey of 1584 reference is made to two furnaces (‘... cum II bass molendinis ferreis voc. furnesses edificatis infra dictum parcum’, ibid., vol. xviii), and also in 1596, PRO, Chancery Proceedings, Eliz. W8/53. Although the forge was in operation throughout the whole of the seventeenth and eighteenth centuries according to various references to forgers in the parish registers (the last of 1795), there is no evidence of the furnace operating after 1694 at which date a founder is referred to, Shropshire Parish Registers, Hereford Diocese, vol. ix, passim, 1909.

Cliviger, see Holme Chapel.

Clydach, parish of Llanellty, Breconshire. There is some late evidence indicating that a small furnace about 12 feet high was erected in 1590 on the mountain slope south of the river Clydach, on the spot on which the Clydach railway station now stands, and that a forge was in the vicinity in 1600, furnace and forge being closed down in 1607. By the same evidence (kindly supplied by Mr. E. Edwards, Gilwern, Abergavenny), a new furnace was built in the Clydach valley on the north bank of the river near Clydach House in 1606, and a new forge in 1615. The new works is supposed to have been erected by one of the Hanburys, Th. Jones, A history of the county of Brecknock, vol. ii, Part i, p. 480, Brecknock, 1809. The works is mentioned in 1704, App. XVI, and in the lists of 1717 and 1790. A larger works was built in 1795, higher up the Clydach valley, the ruins of which are still standing. An illustration is supplied by J. Lloyd, The early history of the old South Wales Ironworks, p. 192, London, 1906.

Coalbrookdale, Shropshire. The Old or Upper Furnace erected by Basil Brooke in 1658, was leased to Abraham Darby in 1709 who reconditioned it and before 1711 successfully commenced smelting with coke. The ruins of the furnace in its present form essentially represent the furnace of 1777, which perhaps was a rebuilding or enlargement of the one built in 1658. The furnace was blown out early in the nineteenth century. A. Raistrick, Dynasty, pp. 102-104. 371
Charcoal Blast-furnaces in England and Wales

Codnor, east of Ripley, Derbyshire. The furnace was erected in 1588, PRO, Chancery Proceedings, Elizabeth, R 11, No. 69. A founder of the furnace is referred to in 1618, Birmingham Reference Library, No. 468993.

Coity Anglia, north-west of Bridgend, Glamorganshire. Licence for 'building a work for melting, making and casting iron sows, and to make iron by forge and furnace' granted to John Thornton of Neen Savage and John Crosse of Cleobury Mortimer 25th August 1589, HMC, Reports on the Manuscripts of Lord de l'Isle and Dudley, vol. 1, p. 29, London, 1925. The works was operated by Willard and Bullen, members of families engaged in the Wealden iron industry, in 1600, Pe., 274.

Combe (or Cursiplotl, or Coushopley) furnace, parishes of Mayfield and Wadhurst, Sussex. The furnace is mentioned first in Articles of Agreement of 2nd October 1651 constituting a partnership between Stephen Penkherst of Trogers in Mayfield who owned the furnace, and Thomas Sackvile of Seddlescombe, Sussex, CRO, Lewes, Dyke-Hutton Collection. It was working in 1664. Straker, p. 288. It was still in the possession of the Penkherst family in 1692, Sussex Archaeological Society, Lewes, Portman Deeds No. 538, and is mentioned last in the list of 1717 (as 'Conshuple') but without any figures of output.

Conster, see Beckley.

Conway furnace, Denbighshire. Only reference in an indenture of 1751, at which date it was operated by Wm. Bridge, formerly of Cranage forge, Cheshire. Barrow-in-Furness, Public Library, Z 26.

Cowarden, parish of Cowden, Kent. By a statement of 1573 operation commenced in 1567-68. Furnace mentioned in 1574 and 1588. In the seventeenth century it belonged to a branch of the Hampshire Tichbornes, and was 'ruined before 1664'. Straker, pp. 150, 226.


Cradley, furnace and forge, on the Stour, Worcestershire. First referred to in 1610 as owned by Lord Dudley and operated by Humphrey Lowe who also held Halesowen furnace (see Halesowen). In 1636 the furnace was worked by Richard Foley, PRO, Star Chamber Proceedings, Chas. I, vol. 321, No. 42. On 20th October 1662 furnace and forge were leased to Thos. Foley of Great Witley, Worcestershire, Dudley Archives, Box 4, Bundle 9. The furnace was still operating in 1774, the forge in 1792, ibid., Box 15, Bundle 8.

Crowhurst, parish of Crowhurst, Sussex. A forge is mentioned in 1574 and 1588, but a furnace not before 1627 at which date it was owned by Sir Thos. Pelham of Laughton, Sussex, who demised furnace and forge to Peter Farnden and his brother Richard for 21 years; it was again leased for 15 years to Peter Farnden in 1647. It was still working in 1664. Hove, Dunn Collection, Box J, 307 and 581; Straker, p. 352; VCH, Sussex, vol. ix, pp. 78-79, London, 1937.

Cuckfield, parish of Cuckfield, Sussex. First direct evidence re a furnace is of 1576 and a forge of 1577. In 1613 a 'filler at the furnis' is referred to. Straker, p. 416.
Charcoal Blast-furnaces in England and Wales

Cunsey, on Cunsey brook, west of Lake Windermere, Lancashire. Furnace erected in 1711–12, continued in operation until 1750. Fell, p. 209.

Cwm Aman, south-east of Aberdare, Glamorgan. The furnace, ruins of which are still in existence, was dated in 1863 when excavations had been made to the sixteenth century, Archaeologia Cambrensis, Third Series, vol. ix (1863), pp. 86–88. There is no early documentary evidence, but the furnace is supposed to have been erected prior to 1720, J. Lloyd, The early history of the South Wales Ironworks, p. 113. The use of an arch and the height of the hearth (5 feet 2 inches), which is unusual for an early furnace, also point to a later date, cf. furnaces in south Yorkshire (1698–1750), Neue. Tr., vol. xix, p. 62.

Cwmfrwdor, between Aberysychain and Pontypool, Monmouthshire. Furnace (also called Blangweul, or, Pontypool furnace), with a forge at Pontypool; first evidence is of 1570 at which date it was demised by the Mineral and Battery Works to Richard Martin, Andrew Palmer, John Wheeler, and Richard Hanbury. From 1577 until 1597 and probably until his death in 1608 Hanbury was the owner. BM, Court Books of the Mineral and Battery Works, vol. i, fol. 93; Lansdowne MS 76; Add. MS 12503. PRO, Exchequer Depositions by Commission, 22 Eliz., Trinity 4, and 39 Eliz., Hilary 23; Exchequer Bills, Bundle 29, No. 24. See also J. A. Bradney, A History of Monmouthshire, vol. ii, pp. 400–401, London, 1921; A. A. Locke, The Hanbury Family, vol. i, p. 141, London, 1916. Concerning the site see D. Walkinshaw, Local Register, or, Chronology of Pontypool, p. 128, 4th edition, Pontypool, 1875.

Darfold furnace situated on the little river Limden near Burgham Farm with a forge on the river Rother, parish of Echingham, Sussex, first referred to in a lease of 16th May 1539 as owned by Thomas Oxenbridge. These may have been the ironworks operated by Mr. Lunford (with the assistance of three Frenchmen in 1544, Page, pp. 66, 181, 200), who borrowed charcoal from Parmingridge in 1547, Pe., 381(1). The lease was conveyed later to Sir Robert Tyrwhitt of Lincolnshire who let it to Thomas Glide of Burwash in 1568 for 10 years. The furnace was extinct before 1653, the forge between 1724 and 1736. PRO, Chancery Decree Rolls, roll 1, No. 57; Proceedings of the Court of Request, Bundle 68, No. 50. Hove, Dunn Collection, Box L, 712. Straker, pp. 297–298.


Dediscom, parish of Rudgwick, Sussex. Only reference to a hammer, i.e., forge, is of 1631. As a furnace pond was farther up the stream, it is likely that a furnace was operated at the same time as the power hammer. Straker, p. 443.

Doddington, Cheshire. Furnace not in operation before 1711, but referred to in the list of 1717, Johnson, p. 55.

Dolgyn furnace, two miles east of Dolgelly, Merionethshire. Many details are supplied by the Diary of John Kelsall who was Clerk of the ironworks from 1714 to 1720, and again from 1729 to 1743. The furnace was built in
Charcoal Blast-furnaces in England and Wales

1718, the first campaign commencing in January 1719; apparently the furnace was abandoned by 1771. Kelsall’s Diary, Friends’ House, London; see also Neve, _Tr._, vol. xxv, pp. 85–86.

Duddon Bridge, Cumberland. Furnace built in 1736, ceased operating about 1866. Barnes, _loc. cit._, p. 84; Fell, pp. 215–216.

Dudley furnace, between the Castle Hill of Dudley and Tipton, Worcestershire. First mentioned in a document of 1st February 1631–32 by which Edward Lord Dudley sold to Wm. Ward of London 30 acres called ‘the Paddock’ in Conygree Park and abutting lands in Tipton, with mines of coal and ironstone and ‘a furnace to make iron’ erected there, Dudley Archives, Box 18, Bundle 11. By a document of 1632 (Box 6, Bundle 4), Conygree Park included Dudley Castle Hill. The ‘furnace of Dudley’ is still referred to in 1642, ibid., Box 3, Bundle 3.

Durham, possibly in the Weardale. Iron ore was mined in 1626 in the west of the Weardale, and also near Chester le Street, north of Durham. Possibly the iron and leadworks owned by a gentleman living within 20 miles of Durham, who was attacked in a pamphlet of 1629 because of excessive wood-consumption, were in the Weardale, and also the Bishop of Durham’s furnace worked by John Hodshons in 1664. _VCH, Durham_, vol. ii, pp. 280–281, 355; BM, Add, MS 18147, fol. 8; Durham, Library of the Cathedral, Mickleton MS No. 91, item 29.

Dyffryn furnace, on the site of the Dyffrin or Aberpennar Mill, close to the boundary between the parishes of Aberdare and Llanwonno, and in the Cynon or Aberdare valley, Glamorgan, was erected between 1564 and 1575 by Jevan Howell, Wm. Relie, and Wm. Darell. It produced ‘rough iron and shot for ordinance’ from 1575 to 1578; the founder was Edward Cavell, a Sussex man, who died in 1578. Apparently, Howell’s share was taken over by Anthony Morley who died in 1587. The furnace was still working in 1591. The forge was in the parish of Llanwonno; it ceased working a fair time before 1638. A second forge termed the ‘New Forge’ stood in the Cynon valley, probably at Llwdcoed between Abercynon and Mountain Ash. PRO, _Chancery Proceedings_, Elizabeth A 2, No. 50; L3, No. 28; M 6, No. 53; M 8, No. 36. _Survey of the Manor of Mistin of 1638_, Cardiff Library, Glamorgan Deeds No. 32.34; W. Llewellyn, ‘Sussex ironmasters in Glamorganshire’, _Archaeologia Cambrensis_, third series, vol. 9, pp. 85–86, London, 1863.

Ebernoe, parish of Kirdford, Sussex. The furnace is referred to by Norden in 1607. It was probably owned and worked by the Smith family who acquired the manor of Ebernoe in 1594 and held it until 1641. The forge for Ebernoe furnace was at Wassell, owned and worked by the same family from 1579 to 1640. G. H. Kenyon, ‘Wealden Iron’, _Sussex Notes and Queries_, vol. xiii, Nos. 11 and 12, Lewes, 1952.

Elmbridge furnace, on the western outskirts of the township of Newent, Gloucestershire, in production from 1692 to 1759. — B. L. C. Johnson, _ECHR_ second series, vol. iv, p. 338.

Eridge, parish of Rotherfield, Sussex. The site of furnace and forge was in Erith Park, owned by the Lords Abergavenny who held the estate, with many others in Sussex, since the Norman Conquest. The ironworks, judging by
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the many Frenchmen who lived at Rotherfield, were probably erected before 1538, Rotherfield, Parish Registers, 1538 et seq. The furnace is mentioned in 1562, Jo., vol. 164, p. 242, and, with the forge, in 1574. The furnace had fallen into disuse before 1667, but the forge was 'continued in hope'. Straker, pp. 257-258.

Ewhurst, parish of Northiam, Sussex. Furnace mentioned in 1664 as being discontinued, but repaired and stocked. Straker, p. 320.


Flaxley furnace near Flaxley Abbey, Gloucestershire, first referred to in 1680, and again in 1695-96 at which date pig iron produced at the furnace (under Richard Knight) was sent to Bewdley, Johnson, p. 53. The furnace is mentioned in 1706 as being owned by Mrs. Bovey who also had two forges, PRO, Treasury Papers, vol. 97, fol. 170. It was in production in 1717 and is mentioned in the lists of 1790, Scrivenor, 1841, p. 361, and 1806, Birmingham, Bolton and Watt Collection. See also Rh. Jenkins, Newc. Tr., vol. vi, pp. 55-58, 62.

Foxbrook, 4 miles north-east of Staveley, Derbyshire. Furnace erected in 1652, VCH, Derbyshire, vol. ii, p. 359; it is mentioned in the list of 1717.

Firth furnace, parish of Petworth, Sussex. According to evidence of 1574, a furnace and a forge in 'Petworth Great Park' were owned by the 'late' Earl of Northumberland, who was beheaded in 1572. The forge was at Mitchell Park. Both were the only iron works referred to in the Court Rolls of the Manor of Petworth from 1537 to 1650. The double furnace mentioned in 1574 as being situated 'neare northe the Chapple' is apparently identical with Firth furnace which was in the immediate vicinity of Northchapel. Firth furnace is not in the list of 1717, but is marked on Budgen's map of 1724. It finally closed down in 1776. G. H. Kenyon, 'Wealden Iron', Sussex Notes and Queries, vol. xiii, Nos. 11 and 12, Lewes, 1952; Straker, pp. 426-429.

Gloucester furnace, see Lamberhurst.

Gornalwood furnace, situated north of Barrowhill and south of the road from Dudley to Himley, in the south-western corner of the parish of Sedgley, Staffordshire. The furnace was demised on 2nd October 1595 by Edward Lord Dudley to Richard Hamnett, his servant, who was his bailiff in 1592. The furnace probably was erected in the same year; in 1597 stone and timber for erecting buildings on the premises were granted to Hamnett. In 1607 it was in occupation of Thos. Hickmans of Gornal. After him and his descendants the land was named 'Hickmans piece'. The furnace was definitely abandoned before 1648 at which date John and Nicholas Guest, of Kingswinford, took a lease of the land including the former furnace pool for 21 years, with the liberty to erect 'any fornace mill or mills'. There is, however, no evidence that they built a new furnace on the land. Dudley Archives, Box 3, Bundle 3; Box 4, Bundles 3 and 8; Box 5, Bundles 5 and 7. PRO, Exchequer Depositions by Commission, No. 3106. The site of the furnace was fairly close to that of the later Hascod furnace.

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Gosden furnace, parish of Lower Beeding, Sussex, erected in 1580, and still operated in 1593. PRO, Exchequer Special Commissions, No. 2913; Depositions by Commission, 30 Eliz., East. 8 and 17. Straker, pp. 417, 436.

Grange furnace, on the Smestow Brook, west of Wolverhampton, Staffordshire. First mentioned in 1636 at which date it was operated by Richard Foley, PRO, State Papers Domestic, Chas. I., vol. 321, No. 42. From 1692–1697 it was worked for a partnership in which the Foley's held a share; it is mentioned last in 1749, Johnson, pp. 23 and 97, note 2.

Craquette, parish of West Hoathly, Sussex. Furnace operated in 1574; it is not in the list of 1717, but was worked in 1761–1769. Straker, p. 236.

Gunn's Mill furnace, on the road from Little Dean to Mitchelldean, Gloucestershire, about halfway between the two places. First mentioned in the list of furnaces in the Forest of Dean made in January 1635 as being owned by Sir John Wynter of Lydney who still owned it in 1640. PRO, State Papers Domestic, Chas. I., vol. 282, No. 127; Gloucester, CRO, D 421/T 23. The furnace was destroyed in the Civil War in 1644, but operating again in 1680, and reconstructed in 1682 according to the date on the lower lintel beam above the casting-aperture, Hart, p. 103; Rh. Jenkins, Newc. Tr., vol. v, pp. 56, 87–88 and Plate xxii; vol. vi, pp. 55, 56, 62. It was in production in 1705–06, 1710–12, 1717–18, and again in 1730–32, Johnson, in ECHR, second series, vol. iv, p. 338; PRO, Audit Office, Various Accounts, No. 1243(5).

Halesowen, furnace and forge, on the Stour, Worcestershire (formerly Shropshire). Erected between 1602 and 1606: in 1602 the former bloom-smithy had ceased to work, PRO, Miscellaneous Books, Land Revenue, vol. 185, fol. 143; in 1606 iron ore was mined for the 'iron mylles' at H. which were owned by Lady Muriel Lyttleton of Frankley, Birmingham Reference Library, Nos. 351727 and 357397, and operated by Humphrey Lowe, PRO, Star Chamber Proceedings, Jas. I., 202(5). The furnace was worked last in 1772, Kidderminster Public Library, MS 161.

Halton, on the river Lune, 2 miles north-east of Lancaster, Lancashire. A charcoal blast furnace is referred to as being erected in 1756 and still operated in 1790, Scrivenor, 1841, p. 360.

Hamsell, parish of Rotherfield, Sussex. By a statement of 1573, operation commenced in 1567–68. The furnace mentioned in 1574 was owned by Alexander Fermor who died in 1582. In the seventeenth century the furnace with its associated forge at Birchen was in the possession of the Bakers. The furnace appears to have been abandoned after Robert Baker's bankruptcy in 1708, and it is not in the list of 1717. Straker, pp. 150, 260–262.

Hascocd or Horsecroft furnace, formerly in the parish of Himley, Staffordshire, the name being still preserved in the name of the sidings at the bottom of Barrowhill incline (in Pensnett Chase) on the Pensnett Railway which are known as 'Askew Bridge' sidings to this day (information kindly supplied by W. K. V. Gale, Sedgley). The site is fairly close to that of the earlier Gornalwood furnace. Dud Dudley in his Metallum Martis (p. 32) claimed to have erected the furnace, but in a Bill presented by him in the Court of Chancery in 1699 he mentioned that the furnace was demised by Edward Lord Dudley.
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on 10th January 1626 to John Smallman who assigned the lease to Francis Heaton of St. Helens, Worcester, in 1631; Dud Dudley claimed lease and assignment were made to both ‘upon special trust and confidence’ for the ‘use, benefit and behoof’ of Dud Dudley. This claim, however, was refuted by the Court in 1635 and the furnace was assigned to Wm. Ward who had bought it with other property from Lord Dudley. PRO, Chancery Proceedings, Chas. I, D 42/9; see also: Decrees and Orders, vol. 173, p. 504 (1638).

Hawkhurst, parish of Hawkhurst, Kent. The furnace was mentioned first in 1574 as owned by Sir Richard Baker of Sissinghurst, discontinued before 1664, but then repaired and stocked, Straker, pp. 321–322. Hawkhurst furnace and forge were amongst the ironworks to be operated for 13 years by a partnership of four which was established on 29th September 1668 (see Horsmonden). The furnace is referred to in the list of 1717, but without figures of output. According to Straker (p. 322) the furnace ‘must have survived to a later period’, but it is not in the list of 1790, Scrivenor, 1841, pp. 359–361.


Heathfield, parish of Heathfield, Sussex, furnace. In 1563 pig iron was bought for Robertsbridge forge from William Reile, Pe., 378/13, who worked Heathfield furnace in 1574 and 1588. It is on record in 1698, and finally ceased about 1787. The furnace is, however, still mentioned in the list of 1790, Scrivenor, 1841, p. 361; Straker, pp. 375–415.

Hendall, parish of Maresfield—Buxted, Sussex. The furnace was situated just below the ancient manor house which was the residence of a branch of the Pelham family early in the sixteenth century, Sussex AC, vol. ix, pp. 220–221. In the list of foreigners made citizens in 1544 four Frenchmen are referred to as working in Pelham’s ironworks; one of them, Isambert Bilet, who came to England in 1514 at the age of fifteen, was buried at Maresfield in 1553, Page, pp. 22, 202, 236, 237; Maresfield Parish Registers (Extracts Sussex AC, vol. iv, pp. 244 et seq). The evidence suggests that Pelham’s ironworks were at Hendall in 1544, and were operated some years earlier. Anthony Pelham acquired Ewood Park, in Surrey, in 1554, and Hendall furnace was possessed by Nicolas Pope in 1574 and 1588, Straker, pp. 397, 452. Apparently it was still working in 1618–20 and owned by Ralf Pope, since there is a reference to ‘yron Sowes’, kept in his custody, CRO, Lewes, Wills and Inventories.

Himley furnace, parish of Himley, Staffordshire. The furnace described as being situated near the Church Hall and the park of Himley was demised by Edward Lord Dudley to Richard Foley of Dudley, yeoman, on 30th June 1625 for 10 years, Dudley Archives, Box 4, Bundle 6. In February 1631, Lord Dudley took over the furnace again, PRO, Chancery Proceedings, Chas. I, D 24/70. It is last referred to in 1638, ibid., D 2/44.

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Holme Chapel, near Cliviger, Lancashire, about halfway between Burnley (Lancs.) and Todmorden (Yorks.). Possibly a furnace was erected first after rights to mine iron ore on Crown property in the township of Cliviger had been granted in 1587–88, PRO, Duchy of Lancaster, Miscellaneous Books, vol. 98, fol. 8r. There is, however, no further evidence until 1690, at which date a blast furnace was being operated by the Spencer partnerships until 1750, A. Raistrick, Neusc. Tr., vol. xix, pp. 54, 56, 78.

Horsmonden, or Serendine furnace, parishes of Horsmonden and Brenchley, Kent. The furnace is mentioned first in Christopher Baker's list of 1574 as owned by Thos. Brattell and worked by Mr. Ashburnham, Sussex Notes and Queries, vol. vii, p. 99, Lewes, 1893. Thos. Brattell or Brattle was a scythesmith at Goudhurst in Kent, and still had some rights in the furnace in 1579 on the 13th April of which year the furnace was demised by Thos. Darell of Scotney, Sussex, to Thos. Dyke of Lamberhurst, Kent, for 12 years, CRO, Lewes, Dyke-Hutton Collection. From about 1596 to 1604 it was occupied by Sir Thos. Wailer after which date it was operated by Thos. Browne of Ashurston, PRO, Exchequer Special Commissions, No. 4143. The furnace was worked by the Brownes, the well-known family of gunfounders, throughout the major part of the seventeenth century, Straker, pp. 162–164, 280. On 29th September 1668 a co-partnership between George and John Browne, Alexander Courthope of Horsmonden, and William Dike of Frant was agreed to for working the furnace together with Hawkhurst furnace and forge, and Bayham forge for 13 years following, Dyke-Hutton Collection, loc. cit. The furnace was still operated in 1689, but probably disused before 1717, Straker, p. 281.

Horsted Keynes, parish of Horsted Keynes, Sussex. The first evidence of a furnace is of 1574, the last of 1668. Straker, pp. 410–411.

Huggetts furnace, parish of Mayfield, Sussex. The first date indicating the existence of this furnace is in a statement of 1573, according to which operations appear to have started in 1543. The furnace is mentioned in 1574, but not in the list of 1664. Straker, pp. 150, 387–388.

Ifield furnace, parish of Bewbush, Sussex. Its existence is indicated first in a contract of 2nd November 1567 by which Philipp Mellherst was obliged to deliver 'sows of iron' from Ifield, to Thos. Blackwell to be worked at the latter's forge at Burningfold (later called 'Dunsfold forge'), in Surrey, PRO, Proceedings of the Court of Requests, Bundle 115, No. 2. The furnace continued until 1643, the approximate date of its closing down, Straker, p. 459 (under 'Bewbush').

Ifton, in the north-western part of Shropshire, near the Welsh border. The only reference to a furnace is in the will of Sir Thos. Myddelton of 6th August 1666 who bequeathed to his grandson his furnaces at Ruabon, in Denbighshire, and at Ifton, W. H. Myddelton, Chirk Castle Accounts, vol. ii, p. 54, Horncastle, 1931. It is not in the list of 1717.

Imbhamms furnace, parish of Chiddingfold, Surrey, erected by Lord Muntague, about 1570, still blowing in 1653, but not worked any longer in 1664. The forge was evidently at Pophall which was sometimes erroneously called a furnace, Straker, pp. 420–421. The forge is mentioned last in 1730, VCH, Surrey, vol. ii, p. 272.
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Iridge, parish of Hawkhurst, Sussex. Furnace marked on maps of 1710 and 1751. No other records. Straker, p. 320.

Kidwelly, Carmarthenshire. A licence to erect a furnace and two forges was granted to George Mynn(e) in 1636, Bo., Bankes Papers, 41/28. With the grant went a licence to convert wood into charcoal within a 12-mile radius of Whitland Abbey, near Carmarthen, which indicates that the site of the furnace was at Kidwelly where a furnace was in production in the early eighteenth century, probably held by Peter Chetle, Johnson, p. 53. The furnace is still in the list of 1717, but not in any of the later lists.

Kinderworth, between Sheffield and Rotherham. Furnace referred to first in accounts of Attercliffe forge of 1585–90, Sheffield, Duke of Norfolk's Estates Office. The ironworks at Kimberworth are mentioned in 1608, Sheffield City Library, Shrewsbury Letters, and in 1628, Bo., MS Selden, supra 116. The last specific reference to the furnace at Kimberworth is in a rental of 1645, Yorkshire AC, 1939, No. 136.

Kirby furnace, Nottinghamshire. On 29th June 1673 Wm. Duke of Newcastle granted wood in Sherwood Forest with the right to erect forges, ironworks, and furnaces to Humfrey Jennens who bequeathed the furnace in his will of 14th February 1690 to his son John Jennens of Birmingham. CRO, Nottingham, DDP/15/61. The furnace is in the list of 1717.

Knareborough Forest, West Riding of Yorkshire. An ironworks on Crimple Beck, erected partly on waste ground of the Forest and partly on the waste of Follifoot, south-east of Harrogate, by the Earl of Cumberland as steward of the honour of Knareborough, is referred to in 1598. PRO, Dukes of Lancaster, Special Commissions, No. 584. The existence of a blast furnace is indicated by a purchase of ‘cast hammers, anvills and diverse other rough yron’ in 1605, bought at Spofforth, near Follifoot, Be., 881.

Knopp, parish of Shipley, Sussex. Furnace belonging to the Duke of Norfolk operated from 1568 to 1604, Straker, p. 418.

Lamberhurst or Gloucester Furnace, parish of Lamberhurst, Kent. Originally there was a forge only, erected in 1548. A furnace was built in 1695 and is mentioned in the list of 1717. A rough drawing was supplied by Swedenborg in 1734. The furnace is referred to in 1782 but not mentioned in the list of 1790. Straker, pp. 75, 78, 269–273.

Lawton, east Cheshire. Furnace erected in 1658 by John Turner, PRO, Depositions by Commission, 1659, Easter 4. It was in operation in the years 1666 to 1711, and is mentioned in the list of 1717, Johnson, pp. 61–62.

Leighton, between the river Severn and the Wrekin, Shropshire. Wood sales for charcoal-burning suggest that the furnace was erected about 1662, Shrewsbury, Reference Library MS No. 3093. From 1681 it was worked by the same partnership which had Willey furnace and various forges (see Willey).

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Lilleshall, Shropshire. A furnace is first referred to in an indenture of 20th June 1591, by which Sir Walter Leveson of Lilleshall demised to Richard Corbett of Moreton Corbett and Vincent Corbett of Peynton 'his iron works, furnaces, forges and hammers' in county Shropshire, PRO, Proceedings of the Court of Request, Bundle 63, No. 74. The site seems to have been south-west of the former Abbey, judging by the site of various coppice woods, demised in 1591, 1592 and 1594 with licence to dig for ironstone and for charcoal burning, CRO, Shrewsbury, 38, Nos. 101, 104, 142. Apparently the furnace was still active in 1628; ibid., No. 112.

Linton furnace close to the Rudhall Brook, 4 miles east of Ross, Herefordshire. The furnace is mentioned in 1680, and again in 1692-99 (but not producing). It is not in the list of furnaces of 1717. — Rh. Jenkins, Neve. Tr., vol. vi, pp. 55, 62; Johnson, p. 40.

Llanelli, see Clydach.

Longhope, east of Micheldean, Gloucestershire. The first reference suggesting a furnace being operated is of 1656, at which date iron ore from the Forest of Dean was carried to Longhope, Hart, pp. 79-80. The furnace is mentioned in 1680, ibid., p. 103; Rh. Jenkins, Neve. Tr., vol. vi, pp. 55, 62. It was in production in 1682, when Thos. Baskerville saw it on his way from Ross to Gloucester, HMC, The Manuscripts of the Duke of Portland, vol. ii, p. 293-294, London, 1893.

Low Wood, on the river Leven, near Backbarrow, Lancashire. Furnace and forge erected in 1748, operation ceased in 1798. Fell, pp. 218-220.


Lydbrook, between English Bicknor and Ruardean, Gloucestershire. The existence of a furnace and a forge in the possession of Robert Devereux, Earl of Essex, is evident from a test of Osmond iron which was forged at the forge from 'raw iron' produced at the furnace, between 1591 and 1594, PRO, Exchequer Depositions by Commission, 39 Eliz., Hl. 23. Two furnaces and two forges are referred to in 1602, ibid., 44 Eliz., Trin. 3. The two furnaces were in ruins before 1617, Lewes, Sussex Archæological Trust, GG 654. In 1612 a new furnace and forge were erected by Wm. Herbert, Earl of Pembroke, on the property which after Robert Devereux's attainer for high treason had been forfeited to the Crown; both were destroyed in the Civil War with all the King's ironworks, in 1644 (see Parkend furnace). In 1663 the furnace called 'Howbrooke' furnace, and Lydbrook forges are referred to, PRO, Exchequer Special Commissions, No. 6080. The furnace was operated by Robert Clayton in 1663-64, CRO, Gloucester, D 421/E6. The furnace, with all the King's ironworks in the Forest of Dean, was finally abandoned in 1674. Three forges at Lydbrook were still in operation from 1717 to 1731, PRO, Audit Office, Accounts Various, No. 1243(5). — See also Rh. Jenkins, Neve. Tr., vol. vi, pp. 54-55, 62.

Lydney, between the Forest of Dean and the Severn estuary, Gloucestershire. A furnace and a forge owned by Sir Edward Wynter of Lydney are
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mentioned first in 1606, but probably they were operated earlier, since there is a reference to charcoal for iron-making, in 1604. In 1617 and 1624 two ironmills are mentioned amongst Wynter's titles. In 1663 a 'New Forge' near Lydney is referred to. The furnace is mentioned in 1680. In 1723 the whole estate of the Wynters was sold to Benjamin Bathurst. The ironworks were still operated by his descendants in 1788, CRO, Gloucester, D 421/T 18, 22, 23, 69. A furnace at Lydney is mentioned in the 'List of Charcoal Furnaces' of 1790, Scrivenor, 1841, p. 361. See also: Rhys Jenkins, Newe. Tr., vol. vi, pp. 50–51, 62; H. R. Schubert, Jo., vol. 173, pp. 153 et seq. Hart, p. 103.

Madeley, north Staffordshire. 'Madeley Furnace' is first referred to by Plot (p. 164) in 1686. It is mentioned in the list of 1717.


Markly, or Rushlake Green, parish of Warbleton, Sussex. The furnace was probably one of the four iron mills in the parish mentioned in 1548. It is traditionally reputed to have been operated before 1557; last referred to in 1655. Straker, pp. 114, 380.

Marshall's furnace and forge, north-west of Maresfield church, Sussex, first mentioned in 1574, evidently operated by Ralph Hogge who owned the manor house of Marshallats at about this date. Last referred to in 1664. Straker, pp. 398–399.

Maryport, north of Workington, Cumberland. Furnace erected in 1752 and worked until 1783. H. R. Schubert, 'The Old Blast-furnace at Maryport', Jo., vol. 172, p. 162. Eventually the furnace was worked with coke, but in the early years with charcoal, since G. Jars (Voyages Metallurgiques, vol. 1, p. 250, Lyon, 1774), who visited the district in 1765, recorded that one of two furnaces near Workington was in blast and a second was going to be erected, but that this second one was destined to be a coke furnace. The furnace is still standing to its full height, but is in a bad state of preservation.

Masborough, Rotherham, Yorkshire. A blast furnace was erected in 1740 and worked by the Walkers still in 1790. Scrivenor, 1841, p. 361.

Mayfield, Sussex. Ironworks are mentioned in accounts of the manor belonging to the Archbishop of Canterbury in 1545. Thomas Gresham who acquired the manor before 1570 had a licence to export 100 cast-iron cannon to the King of Denmark in 1574. The furnace was in operation in 1653; it was discontinued before 1664, but had been repaired. It is, however, doubtful whether it was operated again. In 1712 it was definitely out of use, PRO, SPD, Elizabeth, vol. 95, No. 62. E. M. Bell-Irving, Mayfield, p. 59, London, 1903. Straker, pp. 292–293.

Maynard's Gate furnace, parish of Rotherfield, Sussex, apparently existing in 1562 (Jo., vol. 169, p. 242) was worked by Anthony Fowle who died in 1568, and used for the making of ordnance and shot by Arthur Middleton in 1574, and is mentioned last in 1603. Straker, pp. 254–256.

Mearheath furnace, near Longton, Staffordshire. First referred to in 1686, Plot, p. 93, but it may have succeeded the earlier furnace at Stones. It was a large furnace operated from 1692 to 1717, Johnson, pp. 56–59. It is referred to in 1751 at which date it was operated by John Smith, Barrow-in-Furness, Public Library, Z.26.

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Middleton, Warwickshire. A furnace at M. with a forge at Hints (in Staffordshire) was erected in 1591. Accounts are preserved until 1595, Middleton Papers.

Mill Place, parish of East Grinstead, Sussex. An important furnace, worked by Robert Reynolds in 1574. Discontinued before 1664, but repaired; it is not in the list of 1717, but was used for gunfounding in 1763. Straker, pp. 236–237.


Neath, in Glamorgan. A furnace was on the highway from Neath Abbey to Cwrt-y-betws in the seventeenth century, but the only evidence is a deed of 1694 by which a 'parcel of ground wherein a furnace for the melting of iron ware formerly stood', was demised for the erection of copper works, NLW, Coleman Deeds, No. 829. A new furnace at Neath appeared to be erected in 1708 by John Hanbury (began to blow 6th October, it was called Melin Court furnace, see App. XVI). It is mentioned in the list of 1717. By 1790 it had been converted into a coke furnace, Scrivenor, 1841, p. 360.

Netherfield, see Beech.


Newent furnace, in Oxenhall, Gloucestershire, erected about 1639 by Francis Finch who owned the Manor of Oxenhall. From 1665 to 1668 it belonged to Thos. Foley, and it was still working in 1731, but abandoned before 1779. PRO, Chancery, C 8, Bundle 161, No. 74; Eschequer Depositions by Commission, 20 Chas. II, Easter 37; Audit Office, Accounts Various, No. 1243(5). See also Rh. Jenkins, Newc. Tr., vol. vi, pp. 57–58, 62.

Newland, near Ulverston, Lancashire. Furnace built in 1747, rebuilt in 1770. Production ceased in 1891, the furnace was dismantled in 1903. Barnes, loc. cit., p. 85; Fell, pp. 217–218.

Nithwaite, on the river Crake, Lancashire. Furnace erected in 1736, in production until about 1755, the forge until 1840. Barnes, loc. cit., p. 84; Fell, pp. 211–215.


Oakamoor, near Alveton, Staffordshire. Furnace and forge erected in 1592, by Sir Francis Willoughby. Accounts extending from 1593 to 1608, Middleton Papers.
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Oldlands, parish of Buxted, Sussex. Apparently the furnace, at which parson Wm. Levett began to cast guns in 1543, was at Oldlands, which is mentioned in his will of 1554, Straker, pp. 150, 394–395. Possibly it was the place at which the ‘Ernefounders of Buxted’ worked in 1490, ibid., p. 47.

Old Mill, parish of Mayfield, Sussex. A furnace which had been in the possession of the late Richard Maynard of Rotherfield, Sussex, is mentioned in an inventory of his property and goods in 1618 and 1620, CRO, Lewes, Wills and Inventories; see also Straker, p. 285. The forge, also mentioned in the inventory, probably was Old Moat forge, about ½ mile lower down the river Rother, in the same parish, Straker, p. 286.

Oxenhall, see Newent.


Pannigrige furnace, parish of Penhurst and Ashburnham, Sussex. The furnace was erected in 1542 by Sir Henry Sidney, and supplied the forge at Robertbridge with pig iron until 1562. Starting in 1565 again pig iron was delivered to Robertbridge but then designated as having been ‘bought’. Probably at that time the furnace was already in the possession of the Ashburnhams who definitely owned it in 1574 and 1588. It closed down before 1611. Pe., Nos. 373–378, 382, 383. Straker, pp. 362–363.

Parkend furnace, on the Cannop Brook and below York Lodge in the centre of the Forest of Dean, Gloucestershire. Furnace and forge erected in 1612 on Crown property by Wm. Herbert, Earl of Pembroke, together with a furnace at Cannop, a furnace and forge at Lydbrook, and a furnace and forge at Soudley. All these ironworks, to which two more forges, i.e. Whitecroft, between Parkend and Lydney, and Bradley, near Soudley, were added in 1628–29, were operated by various lessees, and destroyed in the Civil War, in 1644. In 1653 a new furnace was erected, but lower down the brook towards the village of Parkend, and in 1654 a new forge at Whitecroft. Both were abandoned in 1674, and sold for demolition to Paul Foley. H. R. Schubert, ‘The King’s Ironworks in the Forest of Dean’, Jo., vol. 173, pp. 153 et seq.; Rh. Jenkins, Newc. Tr., vol vi, pp. 47 et seq.

Parrock, parish of Hartfield, Sussex, forge first mentioned in 1513, the furnace in 1518, but probably of more ancient origin. Furnace and forge were operated throughout the whole of the sixteenth century until 1600 at least, and must have been abandoned some time after this date since they are not mentioned in the list of ironworks of 1664. Straker, 241–244.

Pashley furnace, parish of Ticehurst, Sussex, erected before 1543 when it was acquired by Thomas May of Ticehurst who died presumably in 1552. The forge seems to have been in the parish of Echingham. Thomas May’s descendants still owned both in 1614. The furnace was abandoned before 1653. Straker, p. 299. VCH, Susses, vol. x, p. 255. L. J. Hodson and J. A. Odell, Ticehurst, pp. 133–134, 154, Tunbridge Wells, 1925.

Penney Bridge, on the river Crake, Lancashire. Erected in 1748, producing last in 1780, finally dismantled in 1791. Fell, pp. 221–222.

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Pentyrch, north-west of Cardiff, Glamorganshire. A furnace was apparently erected before 1600, since between this date and 1609 large quantities of cannon were cast there by Edmund Mathews, the furnace being called the 'old furnace', PRO, Exchequer Special Commissions, No. 4143. The forty cannon for the manufacture of which Bristol merchants applied in 1625 to arm their ships against Turkish corsairs, were apparently cast at Pentyrch, J. Latimer, The Annals of Bristol in the Seventeenth Century, p. 91, Bristol, 1900.

Plas Madoc, Denbighshire. Furnace referred to in the list of 1717.


Pontypool, see Cwmfrewdoer, and Trosnant.

Pontyryn furnace, parish of Merthyr Tydfil, Glamorgan. A furnace at P. (now in Aber-canaid) on the western side of the Taff valley, presumably existed around 1579 which is suggested by a cast-iron fireback of this date found in the district, W. Llewellyn, 'Sussex ironmasters in Glamorganshire', Archaeologia Cambrensis, third series, vol. 9, p. 91, note 2, London, 1863. Another fireback found in the same area was dated 1629 (ibid.). This was apparently the furnace owned by Thomas Erbury of Merthyr in 1629, N.L.W., Bute Muniments Parcel B, No. 2, Box 91. The forge operated by Erbury at the same date seems to have been at Pontygwaith, farther down the valley but on the eastern side.

Poole Bank furnace at Over Whitacre, between Birmingham and Nuneaton, Warwickshire. The furnace was worked in 1692; it is in the list of 1717, and is indicated in a map of Warwickshire, surveyed in 1722–25. Johnson, pp. 24, 32–33.

Pounsley, parish of Framfield, Sussex. According to a statement of 1573 operation commenced after 1543. An 'iron mill' is referred to in 1548, a 'furnace' in 1574, operated by Robert Hodson who had married at Framfield in 1546 and was buried there in 1597. The furnace was discontinued before 1664, but repaired. Framfield Parish Registers. Straker, pp. 113, 150, 391. It is mentioned in the list of 1717, but not as producing.

Redbrook furnace in a hamlet known as 'The Foundry', in Upper Redbrook, on the road to Newland and Staunton, Gloucestershire. It is mentioned first in 1628 as being owned by Benedict Hall of High Meadow, who also had a forge near Monmouth. In a list of January 1635, two furnaces owned by Benedict Hall are referred to, but in 1646 one furnace only. The furnace was still in Hall's possession in 1659 (reference to a 'founder'). The furnace was operated in 1676 (Hart, p. 90) and from 1699 to 1733, and is mentioned in the list of furnaces of 1790 and 1806. PRO, Exchequer Special Commissions, Nos. 5304 and 6080. Lewes, Sussex Archaeological Trust, Gloucestershire Charters belonging to Viscount Gage, GG 934 (of 1659). Rh. Jenkins, Newc. Tr., vol. vi, pp. 51, 63. B. L. C. Johnson, EcHR, second series, vol. iv, p. 338. Scrivenor (1841) p. 361. Birmingham, Bolton and Watt Collection.

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Rievaulx, parish of Helmsley, North Riding of Yorkshire. A furnace and a forge are mentioned first in an account of 1577-78, Be., No. 527. They belonged to the Earl of Rutland. The site of the furnace was close to the rere-dorter of the former Cistercian Abbey, indicated by piles of slag discovered there; the forge was farther down the valley of the river Rye, south of the road from Helmsley to Scawton, H. A. Rye, 'Rievaulx Abbey, its Canals and Building Stones', Arch. Jo., vol. LXXI, pp. 76-77, London, 1900. A new forge was built in 1610-11, Be., Letters and Invoices, 25th May 1611. The old furnace was pulled down and a new one was erected in 1616, Be., No. 532. The last account preserved ends with 1643, Be., No. 539. The ironworks are mentioned last in 1647 at which date they belonged to Lord Francis Villiers, H. A. Rye, loc. cit., p. 77.

Riverhall, furnace and forge, parish of Wadhurst, Sussex, apparently existing in 1562, Jo., vol. 169, p. 242, November 1951, and worked by Nicholas Fowle of Mayfield who still held them in 1574; both furnace and forge are described as ruined in 1664, Straker, pp. 275-276. In Ralph Hogge's complaint of 1573 it was stated that Fowle 'cast gonnies and shott nowe of late within this V or VI years', i.e. since 1567-68, Straker, p. 150. Pig iron also was produced by him in no small quantity, for in 1572 it was stated that he received 3360 cords of wood for the 'blowing' of 150 tons of 'sowes', CRO, Lewes, Dyke-Hutton Collection.

Robertsbridge, furnace and forge, par. of Salehurst, Sussex, erected in 1541. The furnace was in operation from 1542 to 1546 inclusive, after which date it closed down. The forge was pulled down in 1549, but apparently re-built the next year. The furnace was evidently re-erected in 1573, as it was first mentioned again in the list of Wealden furnaces of 1574. It is mentioned last in 1793, and the forge in 1801. Pe., Nos. 369-383. Straker, pp. 310-317.

Rodmore, between Lydney and St. Briavels, Gloucestershire. The furnace was probably erected in 1629 on land belonging to Eleanor, the widow of Edward James; it is referred to as being 'in occupation of' Sir John Wynter in 1633, 'List of the ironworks of the Forest of Dean', PRO, SPD, Chas. I, vol. 282, no. 127. In 1646 this furnace, together with one at Redbrook, a forge at Monmouth and a second forge to be erected at Atkins Mill or Burnt Mill, near Rodmore and in the parish of Alvington, was operated by Robert Kirle, the Governor of Monmouth, in partnership with Captain John Breime, or Brayne, CRO, Gloucester, D 421/9. In 1648-50 and in 1661 the furnace and the forge at Alvington were both worked by Captain Brayne in partnership with John Gonning, merchant at Bristol, who had a quarter share in the furnace, CRO, Ipswich, North Family MSS. In the list of 1717 a forge but no furnace is mentioned. Newc. Tr., vol. vi, pp. 50-53, 63.


Ross, Herefordshire. 'Iron workes at Rosse' are mentioned in an inventory of 1597, Longleaf, Devereux Papers, vol. m, fol. 127. They are also mentioned in papers relating to the debts of Robert Devereux, the second Earl of Essex, who was attainted for high treason and executed on 25th February 1601.
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The ironworks must have been considerable, since they are the only item in the valuation of the Manor of Ross foreign which was valued as ‘well worth per annum £666½½’ (ibid., fol. 107v). Perhaps they were erected shortly after 1568 when the Crown lands in Ross or Walford were granted to Edmund Downing and Henry Best (ibid., fol. 60), who assigned their interest to Robert Earl of Essex. A furnace was still in production in 1659 (ibid., vol. ix, fol. 271v). See also W. H. Cooke, Collections for the History and Antiquities of the County of Hereford, vol. iii, p. 105, London, 1882.


Ruabon, Denbighshire. A blast furnace at R., with a forge at Pont-y-Blew (parish of Chirk), were in operation from 1641 onwards, both being rebuilt in 1661-62. Of the capital invested one-third was supplied by Sir Thomas Myddleton, of Chirk Castle, who died in 1666 and left his ironworks to his two grandsons. NLW, Chirk Castle, F 13, 116 and 13, 148; W. M. Myddleton, Chirk Castle Accounts, vol. ii, p. 236, note 1315, Horncastle, 1931. 1666-1712 the furnace remained in the possession of the Myddletons of Chirk Castle. In a deed of 1702, however, Richard Knight and Thos. Lowbridge are mentioned as being in possession of the furnace. CRO, Shrewsbury, 484/452. The furnace is referred to in the list of furnaces in 1717 and it was still worked in 1732-37. A. Stanley Davies, ‘The Early Iron Industry in North Wales’, Newb. Tr., vol. xxv, pp. 85, 87-89.

Rushlake Green, see Markly.

Sackville furnace, see Brede.

St. Leonards, south-east of Horsham, Sussex, one furnace and two forges. According to a statement made by Thos. Duke of Norfolk who held the forest since the end of 1541 and offered it with the ironworks to the Queen in 1561, the works were leased until 1568. As a lease was generally given for a term of 21 years, it would have started in 1547. A ‘forgeman of St. Leonards’ and a ‘poore boy that died at the Fornaie’ were buried at Horsham in 1614 and 1615 (Parish Registers). Straker, pp. 434-435.

St. Weonards, about half-way between Hereford and Monmouth, Herefordshire. The furnace was on the Garvan Brook, a little to the south of the village, the name being preserved in the present local name of ‘Old Furnace’. The furnace was recorded ‘by oral tradition’ as working in 1645, and was then in the same occupation as the forge at Llancillo. It is mentioned in 1662, 1677, and 1680. It was in production in the years 1707-12, 1714-17, rebuilt in 1720 and again producing in 1725-31. Rh. Jenkins, Newb. Tr., vol. vi, pp. 55-57, 63; vol. xvii, p. 180. B. L. C. Johnson, EcHR, second series, vol. iv, pp. 324, 338. H. C. B. Mynors, ‘Iron Manufacture under Charles II’, Woolhope Tr., vol. 34, p. 6, Hereford, 1953.

Scarlets, parish of Cowden, Kent. Furnace and forge probably worked by ‘Quintyn’ in 1574, and also in 1588. Towards the end of the century the ironworks was owned by the Knights, and in the latter part of the seventeenth century by the Gales. It was still operated in 1703 but it is not in the list of 1717. Straker, pp. 225-226.
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Serdenden furnace, see Horsmonden.

Sharpley Pool, parish of Astley, Worcestershire. The furnace, the ruins of which were discovered in 1924, is supposed to be the one operated by Andrew Yarranton who, by his own testimony, 'entered upon Iron-works' in 1652. T. C. Cantrill and M. Wight, 'Yarranton's Works at Astley', *Tr. of the Worcestershire Archaeological Society*, new series, vol. vi, p. 111, Worcester, 1930.

Sheffield, parish of Fletching, Sussex. Furnace and forge operated definitely in 1546, but probably as early as 1545, since iron was delivered to Peter Bawde, gun founder, from Sheffield at this date, *Arch. Jo.*, vol. 69, pp. 296, 307. The furnace was still operating in 1550, but extinct before 1580, the forge was working in 1653, but laid aside in 1664. Straker, pp. 412-414; Sussex Record Society, vol. 39, p. 72, Lewes, 1933.

Shifnal, Shropshire. A furnace was built on property of the Earl of Shrewsbury in 1564, with a forge at Lizard. The forge was still operated during the major part of the following century, but the only evidence of the furnace being continued is in a letter of 1604 relating to sales of iron to John Jennings in Birmingham and a Mr. Drought in London, with an additional remark referring to Shifnal. Sheffield, City Library, 3.F.M.2. See also H.R. Schubert, 'Shrewsbury Letters', *Jo.*, 1947, pp. 521 et seq.

Shillinglee, parish of Kirkford, Sussex. In 1577 the furnace was referred to as 'a new furnace' set up in Shillinglee Park. It was converted into a malt mill before 1620. G. H. Kenyon, 'Wealden Iron', *Sussex Notes and Queries*, vol. xiii, Nos. 11 and 12, Lewes, 1952.

Shingley, see Chingley.

Slaugham, parish of Slaugham, Sussex. The only evidence of the furnace is of 1574. Straker, p. 404.

Snape, see Scrag Oak.

Socknersh furnace, parish of Brightling, Sussex, first referred to in the will of John Collins dated 1535, *Sussex Notes and Queries*, vol. x, p. 9, Lewes, 1946-47. It passed to his son Alexander who died owner of it in 1550, *VCH, Sussex*, vol. ix, pp. 228-229. It was still in the possession of his descendants in the seventeenth and eighteenth centuries, Straker, pp. 306-307. From 1672-76 it was leased by Thomas Collins of Burwash to Peter Farnden of Sedlescombe and John Roberts of Beckley, founder. Hove Public Library, Dunn Collection, Box L, 764. The furnace is marked on Bodgen's map of 1724. Straker, p. 307.

Soudley, on the Soudley Brook between Blakeney and Cinderford, Forest of Dean, Gloucestershire. Furnace and forge erected by Wm. Herbert, Earl of Pembroke, in 1612; destroyed in the Civil War in 1644. See Parkend furnace.
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Southfrith, between Tonbridge and Tunbridge Wells, Kent. A furnace, the site of which was within the forest or chase of Southfrith, was erected by John Dudley, Duke of Northumberland, and is referred to as 'lately erected' in 1553, Cal. of the Patent Rolls, Philip and Mary, vol. 1, p. 286, London, 1937. It was demised in the same year together with a forge ('finerie') for 40 years, PRO, Special Commissions, No. 1093. Furnace and forge are mentioned last as being in operation in 1670, but are described as 'now demolished' in 1701, CRO, Maidstone, U 38 T1. The site of the forge may have been Old Forge, east of Southborough, Straker, p. 222.

South Wingfield, see Stretton.


Staveley, Derbyshire. Furnace mentioned in 1653, City Library of Sheffield, Beauchief Muniments, No. 80. It is mentioned in the list of 1717.

Stone, Staffordshire. A furnace at Stone, with a forge at Chebsey (west of Stafford), were erected by Sir Walter Harcourt and his son Robert. Sir Walter was living in 1583. The ironworks were evidently erected before 1600, in which year Sir Walter's son and heir Robert was designated 'late owner' of Chebsey. Judging by wood sales from a coppice wood, it seems possible that the works were already in existence in 1574. There is no evidence from later than 1614. Possibly it was continued at Mearheath, near Longton. PRO, Chancery Proceedings, Series I, James I, A 10/11. Stafford, Wm. Salt Library, S.D.8/30. Publications of the Harlean Society, vol. lxxxiii, p. 120, London, 1912.

Stream furnace at Chiddingly, Sussex. In the sixteenth century (1548, 1574, 1588) there was a forge. A furnace is referred to from 1650 to 1664. Straker, p. 384.

Street furnace, 2 miles south of Lawton, East Cheshire, in existence prior to 1700, no other evidence. Johnson, pp. 55, 180.

Stretton, parish of North Wingfield, Derbyshire. A furnace at Stretton mentioned in a bailiff's account of 1593 (Chatsworth, MS 10), and again in 1653 (in Stretton township, Sheffield, City Library, Beauchief Muniments, No. 80). The exact site, however, is not known. It may have been somewhere in the district of Higham in the vicinity of which a bloomsmithy was operated in 1578 (Sheffield, City Library, Shrewsbury Letters). Sales of bar iron are recorded from 1594 to 1606 in the above accounts of bailiffs. Possibly the bloomery near Higham was converted into a forge for the furnace. There seems to have been another forge in the Chase of Crich, south-west of South Wingfield; it was destroyed in the Civil War, and there was 'no bar of iron left' after 1645, Yorkshire Arch. Jo., vol. xxxiv, p. 332, Leeds, 1939.

Strudgate furnace, parish of Balcombe-Ardingly, Sussex. Entries in the parish registers of Ardingly relating to founders at 'Strudgate furnace' and
to hammermen from 1563 to 1594, the earliest being Frenchmen, denote that furnace and forge were operated in this period. Sussex Record Society, vol. 17, passim. London, 1913, and vol. xxxiii, p. 31, Cambridge, 1927. Straker, p. 407.

**Stumlet** furnace, parish of West Hoathley, Sussex, erected in 1534 on property of the Crown and first let to John Levett of Little Horsted on 4th November 1534, PRO, *Duchy of Lancaster, Ministers' Accounts*, Bundle 446, Nos. 7166, 7170, 7176. After his death in 1535, the works were managed for a few years by his brother William, parson at Buxted, *Newc. Tr.*, vol. xix, p. 42. On 5th June 1549 together with Steel Forge in Ashdown Forest it was leased from the Crown by Thomas Gaveller and Francis Chaloner for 21 years (ibid., Bundle 447, No. 7187); it is last mentioned in 1570 (ibid., Bundle 458, No. 7386). See also E. Straker, *A Lost Tudor Furnace found*, *Sussex Notes and Queries*, vol. vi, pp. 217–218, Lewes, 1937.

**Taff** furnace, near Ivy House, Tongwynlais, parish of Whitchurch and Eglwyselan, Glamorganshire. The furnace was apparently erected by Sir Henry Sidney. The date is not known, but it was in operation in 1564, *Pc.*, 170. The position near the river Taff is indicated by the use of a boat for shipping the products to Cardiff and from there to Sussex, *Pc.*, 388. A furnace in the parish of Whitchurch and a forge in the parish of Machen (Glamorgan) both in possession of Thos. Hackett, are mentioned in a survey of 1625, NLW, Bute Muniments, Parcel B, No. 2, Box 91. A furnace at the above-mentioned site is referred to in 1662 and 1663 (‘called Tave furnace’), NLW, Earl of Plymouth Deeds, No. 566, and British Record Society No. 566. It is recorded as a ‘ruined old furnace’ in 1706, Cardiff, Public Libraries, MS 5120, pp. 1 et seq. See also E. L. Chappell, *Historic Melingriffith*, p. 29, Cardiff, 1940.

**Tanfield**, West Riding of Yorkshire. The site of the former furnace is indicated by the field name ‘Furnace Hill’ on the left banks of the river Ure between Tanfield Hall and West Tanfield church. Only evidence is of 1615–17, in which years reference to a founder at Tanfield is made from whom three hammers and one anvil were procured for Rievaulx, Be., Nos. 531 and 532.

**Teddesley**, see Cannock Chase.

**Tilgate**, parish of Worth, Sussex. Furnace first mentioned in 1574. It was operated in the seventeenth century until about 1664. Straker, p. 465.

**Tintern**, Monmouthshire. A furnace (with one forge) is referred to in a survey of the Manor of Portgasseg made in October 1651, NLW, Badminton, No. 1631. In the survey the site of the furnace, coalhouse and ‘other out-houses’ is described as ‘abutting upon the river Wey to the North’. The furnace was in production in 1672–73 and 1675–76, Johnson, *EchHR*, second series, vol. iv, p. 324, and is mentioned in 1680, Hart, p. 103. In 1707–08 it was held by John Hanbury of Pontypool and produced pig iron sent to Blackpool forge in Pembroke, Johnson, p. 53; it occurs in the list of 1717. S. Shaw (*A Tour to the West of England*, p. 204, London, 1789) who visited Tintern in 1788, remarked on the bellows being blown with air compressed in iron cylinders. It was still worked with charcoal in 1790, Scrivenor, 1841,
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p. 361, and is referred to in 1796. The late eighteenth-century furnace was on a different site which is described by Shaw as being on 'a gurgling brook . . . above the village of Abbey-Tintern'. The site is known as 'Old Furnace' about 1 mile up the brook from Tintern Abbey. Rh. Jenkins, *Newe. Tr.*, vol. vi, pp. 55, 58, 63.

**Titchfield**, near Fareham, Hampshire. Furnace and forge erected about 1605 by Henry Earl of Southampton. It is not in the list of 1717, but an iron manufactory is noted on a map of 1776. Literature, see Sowley.

**Tollesley**, Bayham Park, parish of Frant, Sussex. Judging by the bay and the great quantity of glassy slag, a considerable furnace, but no records are preserved, Straker, p. 268.

**Vale Royal**, near Oulton, Cheshire. First evidence of the furnace being operated is in accounts of 1696 to 1712, during which time haematite imported by sea from Cumberland constituted the major part of the charge. From about 1714 to 1720 the Darbys of Coalbrookdale had a share in it. Johnson, pp. 61–64; Raistrick, *Coalbrookdale*, pp. 42–43.

**Wadsley**, near Sheffield, West Riding of Yorkshire. Furnace first referred to in the accounts of Attercliffe forge from 1585–90, Sheffield, Duke of Norfolk's Estates Office. In 1672 it was demised to Lionel Copley of Rotherham, ibid. It is mentioned in a survey of 1683, Sheffield, City Library, Ronksley MSS, vol. 158, No. 9175.


**Warnham**, parish of Warnham, Horsham, Sussex. First evidence relating to a furnace is of 1609. It is referred to in 1621 and 1645, but was ruined in 1664. Straker, p. 441.

**Warren** furnace, parish of Worth, Sussex, worked in conjunction with Woodcock Hammer near Lingfield, Surrey, in 1574. Both were still operated in 1769. By 1787 the furnace was in ruins; the forge was converted into a wire mill. Straker, pp. 214–217.

**West Bromwich**, Staffordshire. A furnace was worked from 1624 to 1632 by Richard Foley who in a law-suit of 1630 contended that it had been a furnace for 40 years 'and more', which would bring the date of erection to about 1590. The defendants, however, opposed him by saying it 'had not been a furnace above the space of 30 years or there about'. PRO, *Chancery Proceedings*, Chas. I, F 13/44; *Deedes and Orders*, vol. 163, p. 66v. It still was in Foley's hands in 1636, PRO, SPD, Chas. I, vol. 321, No. 42. It appears to have been the 'furnace for meltinge and castinge of iron', owned by Thos. Parkes in 1597, Staffordshire AC, 1932, p. 299.

**Whaley**, west of Bolsover, Derbyshire. Furnace mentioned in the list of 1717 (as 'Wanley'), and used until 1770. *VCH, Derbyshire*, vol. ii, p. 360.

**Whitchurch**, on the road from Goodrich to Monmouth. A furnace, with a forge (at Goodrich), is referred to in 1575, owned by George, the sixth Earl of Shrewsbury. In 1628, both were held by a Baronet Kyrle, PRO, *Exchequer Special Commissions*, No. 5304. Evidently he was Sir John Kyrle who
had the lease of the forge in 1629 until 1632, Bo., MS Selden, supra 113, fol. 4; Hereford City Library, LC Deeds, No. 4406. At these dates, however, there is no reference to the furnace, which had probably ceased to work. A furnace was 'newly begun' to be built by George Kemble in 1632, Bo., loc. cit., fol. 48. By 1633 a new forge called Newmill forge, in the parish of Whitchurch, had been erected and was demised to George Kemble. It was still in production in 1646, Hereford, City Library, LC Deeds, No. 4432. Apparently the furnace was rebuilt about 1657 on the foundation of the older furnace; it was still operated in 1672, PRO, Depositions by Commission, 24 and 25 Chas. II, Hilary 15. It is mentioned in 1680, but it was not producing in 1695, nor is it in the list of furnaces of 1717. A reference to 'furnace lease lands in Whitchurch held by Captain Gwilliams' is in an account of the Manor of Goodrich of 1705, Hereford, City Library, LC Deeds, No. 4406. See also Rh. Jenkins Nieuw. Tr.; vol. xvii, p. 179.

Whitnall furnace, between Cheslyn Hay and Cannock, Staffordshire. First mentioned in 1627 as being in the possession of Richard Foley who still operated it in 1636, Stafford, Wm. Salt Library, D 1734; PRO, SPD, Chas. I, vol. 321, No. 42.

Willey furnace, parishes of Barrow and Willey, Shropshire. The first evidence is of 1658 (10 tons of pig iron delivered to Lizard Forges), PRO, Depositions by Commission, 1659, Easter 4. In 1674 it was demised to Philip Foley of Prestwood, Staffordshire, for 21 years, who assigned it on 2nd December to a partnership which also controlled Leighton furnace and the forges at Longnor, Sheinton and Upton, Shrewsbury Reference Library, MS Nos. 3100 and 3230 (1696). The furnace is mentioned in an indenture of 1702, Document in possession of the Lilleshall Co., Oakengates. After a breakdown in 1733 it was rebuilt, and taken over by John Wilkinson and partners in 1759 as the New Willey Company, Raistrick, Dynasty, pp. 61–62, 148.

Wingeworth, south of Chesterfield, Derbyshire. Furnace and forge referred to in 1653, Sheffield City Library, Beauchief Muniments, No. 80. The furnace is mentioned in the list of 1717 and was still operated as a charcoal blast furnace in 1788, VCH, Derbyshire, vol. ii, p. 360.

Withyham or Stonelands, parish of Withyham, Sussex. At W. the Baker family had possessions as early as in the time of Henry VIII. In 1544 five Frenchmen, one of whom was a 'colyer', were made citizens by John Baker, who owned furnace and forge in 1574 and 1588. The furnace was converted into a grist mill, probably before 1676. Page, pp. 19, 27, 142, 207, 253; Straker, p. 253.

Woodman's Furnace, parish of Warbleton, Sussex, probably one of the four ironmills within the parish referred to in 1548. It was operated by Richard Woodman who is mentioned in 1553 to 1557. There is no evidence later than 1574. Straker, pp. 114, 374, 377.

Worth Forest, parish of Worth, Sussex, furnace and forge, accounts of which are preserved from the end of 1546 to 17th January 1549. published Arch. J., vol. LXX, pp. 300 et seq. The works, however, must have been erected earlier than 1544, since at such a date six ironworkers were made 2d—H.L.S.
citizens, Page, pp. 10, 112, 119, 197, 209, 211. One of them, John Gumrie, a
finer who had come in 1534, had a daughter baptised at Worth in 1571
(Parish Registers). The works are mentioned last in 1582. Straker, pp. 460-
464.

Tniskedwin, parish of Ystradgynlais, Breconshire. By a plate, with the date
'1711' on it, found when digging a foundation for a new furnace in 1870,
the furnace must have been in being at such date. It is mentioned in the
list of 1717 and in a deed of 1729, J. Lloyd, *The early history of the old south
APPENDIX VI

Inventory of the Royal ironworks at Newbridge, Sussex, with weights of cast-iron cannon and their chambers manufactured by the tennant Pauncelet Symart, and a note on the erection of a steel forge.1

INVENTORY2

Theis ben(e) the implement(es) and necessaries with other toles of yron belonginge to the Kynge iron milles wythyn the forest of Asshedonne yn the countye of Sussex.

Fyrst to the furnes II furgons of iron and a stokkarde of iron whyth II shovyll(es) of iron and a crochet of iron.

It(em) for the fyner II furgons and a rangarde of iron whyth III peyer of tong(es) and an hoke of iron.

It(em) for the grete hamer (and an anvel and grete ryng of iron for the hamer helfe)3 V peyer of tong(es). It(em) II furgons of iron and an iron hoke.

It(em) a peyer of bellowes for the furneys.
It(em) a peyer of bellowes for the fyner.
It(em) a peyer of bellowes to the hamer.

Weight of cannon and of their chambers4

The weght of III caste gonne of irron with VII chamb(e)rys of yrron foluyng.

Item oonne gonne weyng(e) D C I quarterone XXI lb. }

Item the IIde gone weyng(e) DCC di(midium)

Item the IIIte gone weyng(e) DCC I quarterone XXI lb. }

MMCXLII lb.

1 From Account Roll of 29th September 1509–28th September 1510. PRO, DUCHY OF LANCASTER, MINISTERS’ ACCOUNTS, Bundle 455, No. 7331.
3 The phrase in parentheses was added above the line after ‘grete hamer’, but apparently by the same writer.
4 Written on a small sheet of paper, and affixed to the Account Roll in which the statement about the weight is repeated in Latin. The weights applied are the pound (lb.), and, in addition, the cwt. (C) with multiples (D=5 cwts., M=10 cwts.) and divisions (dimidium= half, and quarterone= a quarter of a cwt.). The various weights are as follows: Gans, 6 cwts., 49 lb., 7 cwts. 36 lb., and 7 cwts. 49 lb. respectively. Chambers, two at 5 cwts. 98 lb. each, four at 3 cwts. 14 lb. each, and one great chamber at 4 cwts. 105 lb. Apparently two chambers were destined for one gun, and the largest chamber may have been made for a gun not included in those enumerated in the account. The centena was 112 lb. (loc. cit. No. 7330).
Chambrys to the same
Item II cambris weyng(e) D C XXXVIII lb. MDCCC di
Item III chambres weyng(e) MCC di(medium) XXXVIII lb.
Item oonne griete chamb(e)re of yrren contenyng(e) in weyght
CCC III quarterons XXI li
Somme to(ta)l MMMMDXVII lb. weight.

According to the account roll the price was 10 shilling pro centena (i.e. a cwt. at 113 lb.). Cannon and chambers were sent to Portsmouth to the Clerk of the Royal Navy for the armament of the battleship 'Le Souvereign' (pro armatur(a) siue defensione cuiusdam magne nauis dicti domini regis voc(ate) le souereyns).

Note on the erection of a forge for the production of steel and iron.¹

No(t)a ad onerand(um) in a(m)n(o sec(undo) de XIII s IIIId de firma unius domus sine fabrice vocat(e) a forge of stele or of iron per quondam Claud(ium) Rombonson de nouo edificat(e) et erect(e) necnon pro VI acr(is) terr(e) prope dict(am) domu(m) siue fabric(am) et III acr(is) terr(e) ex utraque parte cuiusdam riul(i) siue aque ibidem adiacen(tis) ac quendam aque curs(um) ibidem curren(tem) in riulo predicto in parrochia de Hertfeld(e) infra forestam et magnum parcum domini regis de Asshedown(e), habendum et occupand(um) predict(um) domum sine fabricam necnon predict(as) X acr(os) et predict(um) aque curs(um) cum suis part(ibus) predict(o) Claud(io) Rombonson et assignat(is) a festo sancti Mich(aelis) Arch(angel)i . . . ² usque ad finem ter(mini) XL annorum extunc prox(ime) sequent(ium) reddendum inde aut(em) eidem regi XIIIIs IIIId ad festum Pasche et sancti Mich(aelis) Arch(angel)i equ(is) porc(ionibus).

¹ In the margin of the account roll added by the auditor.
² Space left for date of year.
APPENDIX VII

Agreement between the Earl of Rutland and Lambert Seimar concerning the Earl’s bloom-smithies at Rievaulx and Bilsdale and a hammer smithy.

At the Castle of Belvoir, 2nd December, 1541.  

'Fyrst, the said Earle shall bear all the rents of the smythes. The Earle shall repair the said smythe in the howsyng, harthes, chymneys, wheles, waterworke. The Earle shall find all manner of bellowes at his charges. The Earle shall deliver certyn toolles and instrumentes conc. the blome herthes and the stryng harth', according to a bill indented, and keep them in repair. Lambert shall find all other tools not specified in the bill and keep them in repair. 'The Earle shall supply wood to make cole without having anything therefor at the rate of VI dozin and a halfe for every seame of iron to be made at the blome smythes and stryngarth and II dosine to be hade and occuped for the forgyng and makyng of the seid seame of iron at the hamer smythe.'

The Earl shall appoint an officer to bargain with the charcoal burners, the gatherers of ore (i.e. the miners), and the carriers of ore and coal and pay them, and also to the wages of the workmen at bloomhearth and stringhearth.

'The seid officer to receive the iron from the smythe at Laskelle [i.e. in Bilsdale] to the most advantage and the seid officer to deliver the seid iron to the seid Lambard by wyeyght and to pay for the carriage from Laskelle to the hammersmithy.

Lambert shall deliver to the officer half a ton of forged iron for the 'firste seame of iron delivered to him after Martilmas in a(anno) XXXIII H(enry) 8, and the residue of the forged iron and after all charges and XV's. will be paid to the Earl, Lamberd will receive what is more' [i.e. over ½ ton].

From the 1st April anno XXXII Henry VIII [i.e. 1540] Lamberd 'was and ys the reteyned servaunt of the Earle and to have the above seid residences for his wagis and payments and to wear the lyverey of the seid Erle'.

Prescriptions for miners and ironworkers:
'The gatherers of ore to take payne and to cast and carry so that the delf be not stoppyd and gluttyd by them.'

1 Draft copy Archives of His Grace the Duke of Rutland at Belvoir Castle, Misc. MS 106.
2 In a second draft is added; 'some tymne in the forgyng XII blomys wyel be 320, 340 or 360 stone which risith the advantage'. Although the hundredweight of 112 avoirdupois lb. became general in the fifteenth century (Rogers, vol. iv, p. 209), in the present document the cwt. still is 108 lb. as in the Middle Ages. As the stone is 12 lb., the cwt. has 9 stones.

395
Agreement concerning the Bloom-smithies at Rievaulx and Bilsdale

[Reference to various ores]

'Wheras it is lyghtely gotten is dross and whereas it is deepely gotten is the good ure and the more payne to get it, . . . the deeper they go, the better is the ure which will breake in great stones. The drosse will breake in small peaces.

A certayne of the lorde tenantes to take the charge of cariage and to have XXIII hundryth wayd and reckoneyd for the sother, . . . Noo ure to be carid within half a yere after hit be gatherid, but that hit may lyryst cast his fleyys and the mooldes of hit, and in the space it may dryy or els ther will be much losse in the cariage of hit.' . . .

'The stryngardth man to se all the premysse thus ordered.

Too blome smythes to be made ther. Every blome to worke a seame every weeke.

To worke the drosse by hit self and the good iron by hit self.

The stryng man to worke and to delyver too seame every weake and to devyd [i.e. divide] hit in lyke manner.

The smythen to worke as muche wekelyst as cumyth from the stryngardth and to worke the good iron by hit self and the drosse by hit self.

The drosse iron at all manner of forges will worke sooner and [gap in text] and with lesse cost and labor than the tough iron so that the drosse iron wil be as well sold as the tough iron. 9

'Articles & charges as by the informacions of Lambert Semer shall concerne the makynge of every seame of iron which charges are to be paide by Richard Berye officer of . . . Thos. Erle of Rutland [titles] and which charge the saide officer shalle retayne and have agayne to thuse of the saide Erle at the tyme of seling & delyverynge of the sayde iron. VIII foder of ewre will sarue for VI blomys.
VI blomys at every blome XII peces, in the VI blomys IIIxxiXIII pec(es), makinge one seame of yron to be solde for XLs the same which will make halfe a ton of forgid iron.
Every seame in weight is VII score IIII stone being XII to every stone. A tune of forgid yron is IX score VI stone and VII, half a tune is IIIIXX IX stone & IIII.
Every VI pecis frome the stringe harthe is called a dosin & wayithe the XII stone.
XII dosin to a seame & XXIII dosin to II seame'.

'Particular, the charges for every seame

The gettinge of every foder

The cariage of every foder frome
the pitt to the smithie
Coles VI dosin & a halfe XII horse lodes to every dosin
for makinge of every dossyn
for carienghe every dosin Lamberd
findinghe the banysters
for the cariage of a seame from
the blome to ye hamersmythye

\[
\begin{array}{c}
\text{VI}^d \\
\text{X}^d \\
\text{X}^s \text{ VIII}^d \\
\text{III}^d \\
\text{XVIII}^d-\text{IX}^s \text{ IX}^d \\
\text{XVI}^s \text{ III}^d \\
\text{XII}^d-\text{VI}^s \text{ VI}^d \\
\text{XII}^d \\
\end{array}
\]
Agreement concerning the Bloom-smithies at Rievaulx and Bilsdale

The blomers wages for every blome \(\text{VII}^d - \text{III}^s \text{ VI}^d\)

for the Smythie wages of every blome \(\text{VII}^d - \text{III}^s \text{ VI}^d\)

for II axmen for every blome \(\text{IX}^d - \text{III}^s \text{ VI}^d\)

II dosin coles to the forging of half a seame of iron \(\text{V}^s \text{ V}^s\)

[Total:] XLs. Vd. to be paid for the charges of every seame.

[Signed] per me Henricus Dygby, Antony Colse, Robert Thurston, Laurence Foxley. De per moi Lambert Seimar

Byllestale in countye York. Money payd for dyvers staff(e) & necessaries bought & provydyd for the Iron Smythes de XXXIII H(enty) VIII.

\(\text{P}(a)i)d\ for IIII\(acr\) axis, a tuerne,\(^1\) a payer of blome lores,\(^2\) & peare of stryng(e) lores, II lomes\(^3\) & a sheller\(^4\) & a hamer \(\text{VII}^d\)

Item for IIII tuernes & a cantell\(^5\)

Item for fyve tredle pynn(es), syx iron hauk(es),\(^6\)

II lowes,\(^7\) a brod iron skovyll, a forgayn,\(^8\) a sheller, a great hamer, a lyttyll hamer

Item for a whelebarowe

for a buyth to cary water to blome harth

\(\text{Sm}^s \text{ XXII}^s \text{ VI}^d\)

Money rec. by Rych. Bery, officer of the smythe in Byllestale & Ryvaule & baylliff of the wood from 2. XII a\(^o\) XXXIII H. VIII.

Rec. of Lawrence Foxley gent., gen(eral) rec(eiver) to the Earl of Rutland, through Harry Dygby gent., gen(eral) surveyor to the Earl of Rutland

\(\text{do. 16th September 5}^{\text{II}}\)

Total: \(31^{\text{II}}.\)

\(^1\) Tuyere.

\(^2\) A strap or thong. A long thong of leather was laid along each of the bellows boards and fastened by nails, Agricola, p. 364.

\(^3\) A lome was a vessel. Cf. account of 1593, 'paid to the cowper for a great lowrne 3 s.', Middleton Papers.

\(^4\) Chiller. In the account of Byrkeknott (1408-09) 'a chillour', EHR, vol. xiv, p. 518.

In an inventory of 1575 relating to a bloomery in the West Riding of Yorkshire (printed Lloyd, loc. cit., p. 433) a 'blome chiller' for the blomer and an 'eye chiller' for the smith are referred to. The latter was apparently a tool known as a drift for making the eye-holes of the hammer. Such a tool was found among the smith's implements of the late first century A.D. at the Roman Fort of Newstead, Scotland, see above p. 50.

\(^5\) From French chanteau, a piece of cloth; it evidently protected the face of the ironworker from sparks, see illustration, Fig. 20.

\(^6\) Hooks.

\(^7\) Tongs. At Tudeley, in 1550, 'I pair of tonges vocatis loves ferri', Arch., vol. lxiv, p. 163.

\(^8\) An iron bar for working in the hearth. The term used in medieval England was 'andire', 'angire' or 'angisen', Arch., vol. lxiv, pp. 150, 163, 164 (Tudeley, in 1550). At Byrkeknott (1408-09) 'III porres [i.e. pokers] alias naudironis', EHR, vol. xiv, p. 518. In England the term first occurred in an account of 1311 relating to Bolton Priory, Yorkshire ('II auudironis ad camaram prioria'). Th. D. Whitaker, The History and Antiquities of the Deveney of Cram, third edition, p. 468. Leeds, 1876.
APPENDIX VIII

Cast-Iron Firebacks

In the structures the large flakes of graphitic carbon characteristic of grey cast iron are shown (dark coloured), which are responsible for lower hardness and strength, less brittleness compared with white iron. The photo of the sample LA 231 shows the general structure of the casting; the structure of the thicker border, however, shows mottled cast iron due to chilling. A specimen of Sussex cast iron analysed by Percy who in 1886 considered it not less than 200 years old (J., vol. 63, p. 295) had a composition similar to LA 231, i.e. the iron in general is grey in its fracture, but one piece was harder, being grey mottled in part. The analysis is as follows:

<table>
<thead>
<tr>
<th>Graphite G</th>
<th>Combined C</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.890</td>
<td>0.317</td>
<td>0.617</td>
<td>0.774</td>
<td>0.082</td>
<td>0.561</td>
<td>94.759</td>
</tr>
</tbody>
</table>

(by difference)

Chemical and spectrographic analyses of cast-iron firebacks

By courtesy of the British Cast Iron Research Association, Bordesley Hall, Alvechurch, Birmingham

CHEMICAL ANALYSES

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Total C</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
<th>Date</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hastings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pub. Mus.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LA 231</td>
<td>3.58</td>
<td>0.36</td>
<td>0.86</td>
<td>0.074</td>
<td>0.61</td>
<td>1683</td>
<td>6 (similar)</td>
</tr>
<tr>
<td>760</td>
<td>3.55</td>
<td>0.65</td>
<td>0.63</td>
<td>0.070</td>
<td>0.62</td>
<td>16th cent.</td>
<td></td>
</tr>
<tr>
<td>763</td>
<td>3.97</td>
<td>0.93</td>
<td>1.64</td>
<td>0.170</td>
<td>1.43</td>
<td>'Royal Oak'</td>
<td>13</td>
</tr>
<tr>
<td>769</td>
<td>3.27</td>
<td>0.78</td>
<td>0.76</td>
<td>0.058</td>
<td>0.66</td>
<td>?16th cent.</td>
<td></td>
</tr>
<tr>
<td>794</td>
<td>3.99</td>
<td>0.65</td>
<td>0.82</td>
<td>0.048</td>
<td>0.47</td>
<td>1707</td>
<td>15</td>
</tr>
<tr>
<td>802</td>
<td>3.69</td>
<td>0.64</td>
<td>0.94</td>
<td>0.068</td>
<td>0.57</td>
<td>Middle of</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>806</td>
<td>3.64</td>
<td>0.52</td>
<td>0.42</td>
<td>0.086</td>
<td>0.56</td>
<td>1586</td>
<td></td>
</tr>
<tr>
<td>809</td>
<td>3.65</td>
<td>1.00</td>
<td>0.92</td>
<td>0.060</td>
<td>0.55</td>
<td>1642</td>
<td></td>
</tr>
<tr>
<td>No number</td>
<td>3.71</td>
<td>0.92</td>
<td>0.34</td>
<td>0.078</td>
<td>0.61</td>
<td>?16th cent.</td>
<td></td>
</tr>
<tr>
<td>Liège, Musée</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Archéologique</td>
<td>3.59</td>
<td>1.07</td>
<td>0.89</td>
<td>0.03</td>
<td>0.72</td>
<td>1548</td>
<td>p. 224</td>
</tr>
<tr>
<td>Arlon, Musée</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Archéologique</td>
<td>3.75</td>
<td>1.14</td>
<td>1.58</td>
<td>0.03</td>
<td>0.62</td>
<td>1548</td>
<td></td>
</tr>
</tbody>
</table>

1 Samples kindly supplied by J. Manwaring Baines, B.Sc., Curator.
1. Boards with vines. Lewes, John Every Bequest

2. Rope line designs (crosses and pentagram). Lewes, John Every Bequest

3. Designs as in 2. Musée Gaumont, Virton, Belgium

4. Rope lines and firelog. Lewes, John Every Bequest

5. Founder's hand and pair of compasses. Lewes, Museum of Sussex Archaeological Society

6. Medley of Armorial bearings. Lewes, John Every Bequest
7. Arms of Queen Elizabeth I, Leicester Museum, Guildhall branch

MOULDED FROM ONE-PIECE MODELS (8-15)


10. Commemorating the defeat of the Spanish Armada in 1588. Lewes, John Every Bequest (fragment).


13. ‘Royal Oak’ or ‘Oak of Boscobel’ commemorating the escape of Charles II after the battle of Worcester in 1651. Hastings Museum.

14. Biblical subject (King David sacrificing) in Dutch style dated 1661. Lewes, John Every Bequest.

Microspecimens: LA 760 (sixteenth century) LA 809 (dated 1642)
LA 231 (dated 1683) LA 794 (dated 1707)
(All: x 45 Diameters)
### Cast-Iron Firebacks

**SPECTROGRAPHIC RESULTS FOR TRACE ELEMENTS**

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Ni %</th>
<th>Cr %</th>
<th>Cu %</th>
<th>Ti %</th>
<th>Va %</th>
<th>Sn %</th>
<th>Pb %</th>
<th>Sb %</th>
<th>As %</th>
<th>B %</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA 231</td>
<td>n. d.</td>
<td>0.003</td>
<td>n. d.</td>
<td>0.01</td>
<td>0.03</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>0.01</td>
</tr>
<tr>
<td>760</td>
<td>0.03</td>
<td>0.002</td>
<td>n. d.</td>
<td>0.01</td>
<td>0.03</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>0.001</td>
</tr>
<tr>
<td>763</td>
<td>0.03</td>
<td>0.01</td>
<td>n. d.</td>
<td>0.01</td>
<td>0.03</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>0.001</td>
</tr>
<tr>
<td>794</td>
<td>0.03</td>
<td>0.002</td>
<td>n. d.</td>
<td>0.01</td>
<td>0.03</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>0.001</td>
</tr>
<tr>
<td>802</td>
<td>0.03</td>
<td>0.002</td>
<td>n. d.</td>
<td>0.01</td>
<td>0.03</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>0.001</td>
</tr>
<tr>
<td>806</td>
<td>0.03</td>
<td>0.002</td>
<td>n. d.</td>
<td>0.01</td>
<td>0.03</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>0.001</td>
</tr>
<tr>
<td>809</td>
<td>0.03</td>
<td>0.005</td>
<td>n. d.</td>
<td>0.01</td>
<td>0.03</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>0.001</td>
</tr>
</tbody>
</table>

(n. d. = not detected)

Molybdenum, aluminium, tungsten, cobalt, bismuth, and tellurium not detected.
APPENDIX IX

Implements of the Forge in the Forest of St. Leonards, Sussex, 24th June 1573. ¹

Omnia et omnimodi implementa et utensilia necessaria pro fabricacione ferr(i) et operatione eiusdem subsequent(i), videlicet tria paria magnorum forcipium vocat(orum) tonges, tria paria parvorum forcipium pro malleo ferreo vocat(o) the hamer, quattuor paria magnorum forcipium et tria paria parvorum forcipium pro le hamer, quattuor paria magnaorum forcipium et duo paria parvorum forcipium pro duobus les fineries, quattuor furgons, duos annulos ferri, unum tragulum vocat(um) a slede, duo les squashes, duo parva mallea, quinque les clambes, unum le ravel, unum le havet, unum farculum ferri voc(atum) an yron shovell, octo les plates pro les fineries et tres les plates pro molendino malleolo, tres magnos malleos pro incudo vocat(o) le Andefelde, duos incudos vocat(os) Andefeldes, tria paria follium cum eorum apparat(u) et necessar(iis), centum les bellowesnailes, tres corbes vocat(os) basket(es) pro carbonibus, unam acirnamb vocat(um) a whelebarrowe, unum le crockett ferri ad quod ferrum operatum apponitur, unam ceruram, unum clavem pro hostio domus vocat(ae) the storehouse, ac omnia alia necessaria infra predict(um) molendinum vel domos eiusdem molendini apta et idonea pro factur(a) et fabricatione ferri cum eorum partium universis.

¹ PRO, Patent Rolls, Elizabeth, No. 1103, Membrane 2.
## APPENDIX X

Campaign and Output of the Furnace at Rievaulx in Yorkshire, in 1591-92


<table>
<thead>
<tr>
<th>Date</th>
<th>Sows and pigs</th>
<th>Weight</th>
<th>Cast ware</th>
<th>Weight</th>
<th>Total weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct.</td>
<td>23</td>
<td>one sow</td>
<td>11 cwts.</td>
<td></td>
<td>4 tons 16 cwts.</td>
</tr>
<tr>
<td>24</td>
<td></td>
<td>9 cwts. 2 stones</td>
<td></td>
<td></td>
<td>2 stones</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>11 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td></td>
<td>12 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>1 brossen&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
<td>11 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>2 sows</td>
<td>13 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>13 cwts. 4 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>13 cwts. 2 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td></td>
<td>16 cwts. 2 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>16 cwts. 4 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov.</td>
<td>1</td>
<td>17 cwts. 4 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>15 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>15 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>16 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>15 cwts.</td>
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1 Crossed out in the text.

2 This entry which makes the total number of bottom plates four, later was corrected by the auditor who stated that only the first two were bottom plates.

402
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<td>2 plaites: 5 c.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>11 cwts. 6 stones</td>
<td>2 plaite: 4 c. 4 st.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>17 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>17 cwts. 2 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>15 cwts. 4 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>11 cwts. 6 stones</td>
<td>2 plates: 6 c. 2 st.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>14 cwts. 6 stones</td>
<td>2 plaite: 5 c. 2 st.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>17 cwts. 2 stones</td>
<td>1 chaffery plate 2 c. 6 st.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>16 cwts. 6 stones</td>
<td>1 plate: 3 c.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>12 cwts. 2 stones</td>
<td>1 other chaffery plate 3 c. 4 st.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>8 cwts.</td>
<td>1 anvell: 5 c. 2 st.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>11 cwts.</td>
<td>1 hurt: 1 c. 2 st.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>18 cwts. 4 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>12 cwts. 2 stones</td>
<td>1 hammer: 5 c.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>13 cwts.</td>
<td>1 hammer: 5 c.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>18 cwts. 2 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td>17 cwts. 4 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>18 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>17 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
<td>16 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td></td>
<td>18 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
<td>19 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>19 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td></td>
<td>18 cwts. 2 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td></td>
<td>19 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
<td>18 cwts. 2 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td></td>
<td>17 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>17 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td></td>
<td>17 cwts. 2 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

405
### Campaign and Output of the Furnace at Rievaulx, 1591–92

<table>
<thead>
<tr>
<th>Date</th>
<th>Sows and pigs</th>
<th>Weight</th>
<th>Cast ware</th>
<th>Weight</th>
<th>Total weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr. 1</td>
<td></td>
<td>18 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>16 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>17 cwts. 4 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>16 cwts. 4 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>17 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 &amp; 7</td>
<td></td>
<td>18 cwts. 4 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>20 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>20 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>20 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>17 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>17 cwts. 6 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>20 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>18 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>19 cwts. 4 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>19 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>19 cwts. 4 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>18 cwts. 4 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td>18 cwts. 4 stones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>one pigge:</td>
<td>9 cwts.</td>
<td>1 hammer:</td>
<td>5 c.</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>18 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>one pigge:</td>
<td>9 cwts.</td>
<td>1 hammer:</td>
<td>5 c.</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>one pigge:</td>
<td>7 cwts.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Graph of furnace output**

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APPENDIX XI

Inventory of the Iron Mine at Balliregan, county Waterford, province of Munster, Ireland. 30th March 1622

An Inventory of such necessarye as appertaine to the myn worke and their resident this present 30th of March 1622

Inpr (imis) on (e) great wheele now goeinge, th appertennances belonginge: a timbred and planked pomp shaft, a hutch of plank(es), a plompe of forty foote longe, a ragge with 20 thornes of yron, a great chain of 105 foote longe. Item on (e) great wheel standinge, with a plomp shafte, a hutch of plank(es), a ragge with 12 thorns of yron, a plomp of 40 foote longe. Item parcel of great chain that did appertaine to the said ould wheel conteyneing 140 foote.

Item a borjer iterum of yron to bore plomp(es) conteyneing 15 foote. Item byts fitted and suitable to that purpose—7
Item ould brazes of catt yron in the storhouse—2
Item ould gudgeons of cast yron not usful—4
Item pigg(es) of 2 c w(ei)ght to weigh myn at Balliregan—2
Item a pitch pot for the boat(es) and other occasjon—1
Item an old hand plomp ragge with 7 small thorns.
Item small chain for such purpose containinge foote 18
Item square piecees of timber usful for plomp(es)—3
Item 3 small boat(es) for myn carrejage, nomber—3
Item planked key(es) to lay myn upon in nomber—2
Item floodgat(es) for and pertayninge to the boat leat—9
Item troughes to bring water to the wheele—400 foote
Item on(e) ould cable to boye the chain—1
Item on(e) hand pomp of 10 foote—1
Item on(e) hurt of cast yron usful in the chain—1
Item handles of yron for a hand plomp ragge—2

March 30th 1622

Peter Baker

1 Chatsworth, Archives of the Duke of Devonshire, Cork MSS, vol. 13, No. 3.
2 Corruption of plomp, i.e. pump.
3 Borer.
4 Hoist.
APPENDIX XII

Inventory of the Royal Ironworks in the Forest of Dean, 1635

A detailed survey of the state of the King's four furnaces and five forges is supplied by an 'Inventory, Taken 24th-28th September, 1635,' on the occasion of their lease to Sir Bainham Throckmorton and his partners (see p. 187). An abstract of the inventory was published (H. G. Nicholls, The Forest of Dean, pp. 272-277, London, 1858), based on a copy of about 1780, but it contained many substantial errors.

The first of these documents (subsequently referred to as document A) was found with other papers of Sir John Bankes, Attorney-General from 1634 to 1640, at Lydney Park, in Gloucestershire, in 1949. The Bankes' papers were transferred to the County Record Office at Gloucester, and subsequently to the Bodleian Library at Oxford where they are at present. Document A (Bankes Papers 5/50) is the original draft examined and signed by Charles Harbord, Surveyor General, who headed the Commission which made the inventory.

The second document (subsequently referred to as document B) was evidently the copy of the inventory which was annexed to the specimen of the lease given to John Gunning, of Bristol, one of the partners. It is now among the Records of the Gunning family which constitute a part of the North Family Manuscripts, preserved at present at Ipswich, East Suffolk Record Office. Document B is a copy of document A, but with one main difference, viz., the section dealing with Soudley Forge is placed between the sections dealing with Parkend and Whitecroft forges in B, but at the end of the text in A. Occasionally there is a misreading in B, e.g., the figure indicating the extension of timber building at the hutch of Parkend furnace is '14' feet in A, but this number is blotted and difficult to read, and it is replaced in B by '16' feet, i.e., 2 feet too many. Further, in the inventories of the forge implements a clearer distinction between chafery and fineries is made in A. For these reasons, this publication is based on A, but variations in B are referred to in the footnotes.

The text of the inventory is as follows:

FOREST OF DEANE. An Inventorie of his Ma.'s Ironworkes in the said Forest with the implements belonginge to the same, taken the 24th, 25th, 26, 27 and 28th of September 1635 by Charles Harbord Esq.  

1 Omitted in B.
surveyor general, James Kyrle and Charles Bridgman Esqs. and others, by virtue of his Ma.\textsuperscript{14} Commission under the scale of the Exchequer dated 17\textsuperscript{1} Junij last past to them and others directed in that behalfe.

LYDBROOKE FORNACE built about 3 yeares since, 23 foot square at the bottome and 23 foot deepe, much crackt, in the front whereof is 1 sowe of iron and 2 sowes over the tewyron.

The water wheel 23 foot diameter, new made about one yeare since, on the shaffe whereof are 6 iron hoops, 2 gudgeons and 2 brasses: in good repaire.

The bellowes open, with leathers, nayles, girt(es), and irons.

A stone buttresse 10 foot square behind the fornace to strengthen it.

The fornace house 92 foot about, the wallies thereof of stone 10 foot highe, roofed over and tyled.

A peece of wall to support the bridge of the fornace, 22 foot longe, 11 foot highe, with a halfe wall adjoyninge, to keepe up the banke, 19 foot longe and 6 foot highe.

The bridgehouse 21 foot square, 8 foot highe in sydewall, the bridge double plankt, the rooffe uncovered, built one yeare since.

The fence walls thereunto 10 foot highe, made of tymber and wattle.

The troughe\textsuperscript{2} leadinge the water to the wheel 33 foot longe close, and 50 foot longe underground.

A myne kilne\textsuperscript{3} defective, with 6 pieces of cast iron in the draught holes, of about 5 c. weight, built about 4 yeares since.

In the fornace watercourse, at the waste, a trowe 22 foot longe, 2 foot square, open and borne by 2 pieces of wall, whereof one\textsuperscript{4} 16 foot longe and two foot and halfe thicke, the other 15 foot longe and 7 foot thicke.

The hutch leadinge the back water from the wheel, not made by theis\textsuperscript{5} farmers, 30 foot longe, 8 foot deepe.

A founders house, of tymber and wattle, tyled, with a dormer and a stone chimney, floored all over, 32 foot longe, 16 foot broad and ten foot in sydewall, built about 20 yeares since.

Three poore thatched cottages whereof one built by the present farmers.

\begin{center}
\begin{tabular}{lcl}
Longe ringers & & 4 \\
short ringers & & 4 \\
synder shovels & & 4 \\
sledge\textsuperscript{6} & & 1 \\
cole rakes & & 2 \\
handhammer & & 1 \\
placket & & 1 \\
gage & & 1 \\
A woooden beame with iron chaines, triangles and 10c weight of raw iron. & & A new pair of bellowes\textsuperscript{7} bords, readie sawed.
\end{tabular}
\end{center}

The repair of the fornace to make it fit to work (as it is estimated) will cost about fiftie pounds.

CANNOP FORNACE, now bloweing, built for the most parte and the rest repayed by the new farmers about four yeares since, 22 foot square at

\textsuperscript{1} In B: the XVIIth. \hspace{1cm} \textsuperscript{2} B: trowe. \hspace{1cm} \textsuperscript{3} B: kil. \hspace{1cm} \textsuperscript{4} B: one is 16 foot longe. \\
\textsuperscript{5} B: these. \hspace{1cm} \textsuperscript{6} B: slegges. \hspace{1cm} \textsuperscript{7} B: bellowes; boards ready sawed.
the bottome, in the front whereof are 4 sowes of iron and 3 sowes in the tewyron wall.

The wheele 22 foot diameter, on the shafte whereof are 7 iron hoops, 6 iron cambes weyceinge about IVC, 2 gudgeons and brasses, all in good repaire, and new made about 3 yeres since.

The fornace house built of tymber by the said farmers about 4 yeares since, in repaire.

The bridge house 48 foot longe 21 foot broad and 9 foot highe in sidewalls, built about 2 yeares since, the bridge built about 4 yeares since, covered with bord(es) and bottomed with planke.

A trowe leadinge the water to the wheele, cut out of whole tymber and ledged on the top, 1 foot broad at the bottome, and 1 foot and a quarter deep, and 225 foot longe, new made about 4 yeares since and now in repaire.

The hitch leadinge the water from the wheele, 5 foot square, 85 foot longe.

The fornace keepers cabin built of tymber by the present farmers and covered with boards.

A cottage neere the said fornace built by the workemen of that fornace, now enjoyed by the filler there, and not belongeinge to the said workes.

A house wherein the clarke of the said fornace dwelleth, with a little stable adjoyninge, built by the present farmers.

A house adjoyninge to the clarke house, now inhabited by the founder.

A cabin for the myne cracker.

A myne kilne not in repaire wherein are 5 pigs of iron.

Implementes of Cannop1 fornace

<table>
<thead>
<tr>
<th>Item</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>The bellowes furnished, defec-</td>
<td></td>
</tr>
<tr>
<td>tive in the leathers</td>
<td></td>
</tr>
<tr>
<td>water trowes</td>
<td>3</td>
</tr>
<tr>
<td>grindstone</td>
<td>1</td>
</tr>
<tr>
<td>longe ringers</td>
<td>10</td>
</tr>
<tr>
<td>short ringer²</td>
<td>1</td>
</tr>
<tr>
<td>constable</td>
<td>1</td>
</tr>
<tr>
<td>mouldinge ship³</td>
<td>1</td>
</tr>
<tr>
<td>castinge ladles</td>
<td>2</td>
</tr>
<tr>
<td>cinder hooke</td>
<td>1</td>
</tr>
<tr>
<td>placket</td>
<td>1</td>
</tr>
<tr>
<td>cole baskets</td>
<td>12</td>
</tr>
<tr>
<td>myne hammers</td>
<td>2</td>
</tr>
<tr>
<td>myne shovels</td>
<td>2</td>
</tr>
<tr>
<td>cole rakes</td>
<td>2</td>
</tr>
<tr>
<td>myne rakes</td>
<td>2</td>
</tr>
<tr>
<td>bashes</td>
<td>2</td>
</tr>
<tr>
<td>ladder of 14 rungs</td>
<td>1</td>
</tr>
<tr>
<td>buckstaves</td>
<td>2</td>
</tr>
<tr>
<td>tewyron hooke</td>
<td>1</td>
</tr>
<tr>
<td>iron tempe</td>
<td>1</td>
</tr>
<tr>
<td>cinder plate</td>
<td>1</td>
</tr>
<tr>
<td>dam plate</td>
<td>1</td>
</tr>
<tr>
<td>wheele barrowes</td>
<td>4</td>
</tr>
<tr>
<td>great sledge</td>
<td>1</td>
</tr>
<tr>
<td>tewyron plate, cast</td>
<td>1</td>
</tr>
<tr>
<td>tunnel plate</td>
<td>1</td>
</tr>
<tr>
<td>gage</td>
<td>1</td>
</tr>
<tr>
<td>A crackt wooden beame and</td>
<td></td>
</tr>
<tr>
<td>scales, with triangles furn-</td>
<td></td>
</tr>
<tr>
<td>ished, and a tun of iron pigs</td>
<td></td>
</tr>
<tr>
<td>used for a weight.</td>
<td></td>
</tr>
<tr>
<td>Colliers hurdles 8 dozen</td>
<td></td>
</tr>
<tr>
<td>New firket</td>
<td>1</td>
</tr>
<tr>
<td>3C and an halfe of raweiron</td>
<td></td>
</tr>
<tr>
<td>upon the bellowes poizes.</td>
<td></td>
</tr>
</tbody>
</table>

The⁴ repaire of the defects of this fornace will cost (accordinge to an estimate thereof) about seven pounds thirteen shillings and foure pence.

PARKE-END FORNACE. The bodie thereof 22 foot square at the bottome, repayred by the present farmers about 4 yeres since, and the backer wall of the fornace and parte of the wall over the bellowes then built from the foundacion. In the front thereof two broken sowes of iron, and there

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¹ B: Canoppe.   ² B: ringers.   ³ B: shippe.   ⁴ In A this section is in a marginal note, but in B it is in the text.

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hath been one more which is taken thence and is lying near the door of
the furnace house, and there are 2 sows of iron in the tewiron wall.
The furnace body and the bindeinge beames thereof crackt and insufficient
to worke.
The water wheele 22 foot diameter with his shaft whereon are 7 iron
hoops, 6 cambes, 2 gudgeons, and brasses, in reipare.
The furnace house built with stone 22 foot square and 9 foot high in the
side walls, the roofe good except one little breach by the bridge and tyled,
built about 4 years since and now in reipare.
A penthouse under the furnace.
The bridgehouse 42 foot long 22 foot broad the sidewalls 8 foot and
halfe1 highe, covered with boards, double bottomed with planke upon
stronge sleepers, with fence walls, built about 4 years since and in reipare.
Trowes cut out of sound tymber 100 foot longitude, covered with planke.
Another watercourse 2 foot and halfe broad, and 46 foot longe, built with
stone on both sides and covered with planke, in which is a cast iron grate.
A watercourse on the north side of the said furnace about halfe a mile
longe with a bay at the head thereof with a small breache therein, wants
scowring, otherwise good.
A watercourse of about halfe a mile longe on the south side of the furnace.
The hutch 6 foot deepe, 3 foot broad, 70 foot longe, whereof 36 foot
built of stone and 142 foot of tymber, all covered with planke and in reipare,
but the streame stopped below the hutch with cinders.
A house enjoyed by the founder.
A cottage adjoyning thereunto.
A cabbin for the bridgeserver 18 foot longe, 11 foot broad built of tymber
and covered with boards.
A cabin adjoyning to the furnace for the furnace keeper.
A faire house 3 storyes highe, tyled, the ends built with stone and the rest
with tymber, 50 foot longe, 16 foot broad, with a crosse building in it 16 foot
square, with 2 stables of tymber belonging thereunto, in reipare.
A small cottage now enjoyed by William Wayte.
The myne kilne decayed in the inside, and the pigs of iron taken from the
draughts thereof.

| Implements of Parke-end furnace | wheel barrowes | myne hammers | cole rake |
| The bellowes open with the iron furniture belonging defective in the leathers | 2 | 2 | 1 |
| buckstaves | 2 | 1 |
| damplate | 2 |
| cinder plates | 2 |
| tewiron plate | 1 |
| dam hooke or stopping hooke | 1 |
| iron shovels | 4 |
| ringer | 9 |
| cole baskets | 6 |
| Beame with scales, hookes, triangles and linkes with halfe a tun of rawe iron for a waite3 |

The reipaire of the defects in this furnace (accordinge to an estimate thereof made) will cost about threescore pounds.

1 B: a halfe.  
2 B: 16.  
3 B: weight.
SOWDLEY FORNACE

The body thereof 28 foot square at the bottome and 24 foot square at the top, in the front whereof are 4 sowes of iron, and 2 sowes over the tewyon, and fourne longe bars of wrought iron to keep in the corner posts, in good repair, seeminge one small defecte in the inside of the fornace.

The water wheele 22 foot diameter, upon the shafte whereof are 7 hoops of iron, 6 cambes, 2 gudgeons, and brasses, in repaire.

The fornace house and penthouses made of stone 8 foot highe and 186 foot in circuit, tyled for the most part the rest boarderd.

The bridge and bridge house decayed and parte of the bridge house fallen downe.

A coleplace 61 foot longe, 40 foot broad, whereof one side and the 2 ends are walled about with a wall 7 foot highe, and 4 foot thick.

A myne kilne wherein are 10 pieces of rawe yron, in repaire.

Five little cottages on the north side of the streame there.

The founders house built of stone 2 storeys highe, 20 foot longe and 14 foot broade, with a penthouse adioyninge covered with boards.

The trowes leadinge the water to the wheele 2365 foot longe much decayed.

A dam about a mile above the fornace, at Cinderford, 300 foot longe, 12 foot broad on the top, and 25 foot highe, faced and backed with turfe, with a ground goyte and a highe trowe thowre1 the bay, with a fludgate2 of three gates 36 foot longe, 12 foot broad and 6 foot deepe, with a little horsebridge over it, ranged with tymber and aproned3 with planke.

Another dam about halfe a myle higher on the same streame 720 foot longe with a sluice and a ground trowe, some what defective in the face thereof.

 Implements of Sowdley fornace

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>The bellowes open the leathers</td>
<td>1</td>
</tr>
<tr>
<td>halfe wore</td>
<td></td>
</tr>
<tr>
<td>longe ringers</td>
<td>3</td>
</tr>
<tr>
<td>constable</td>
<td>1</td>
</tr>
<tr>
<td>short ringers</td>
<td>9</td>
</tr>
<tr>
<td>dam hooke</td>
<td>1</td>
</tr>
<tr>
<td>placket</td>
<td>1</td>
</tr>
<tr>
<td>cinder hooke</td>
<td>1</td>
</tr>
<tr>
<td>gage</td>
<td>1</td>
</tr>
<tr>
<td>sledge</td>
<td></td>
</tr>
<tr>
<td>fornice shovels</td>
<td>8</td>
</tr>
<tr>
<td>cinder plate</td>
<td>1</td>
</tr>
<tr>
<td>dam plate</td>
<td>1</td>
</tr>
<tr>
<td>tunnel plate</td>
<td>1</td>
</tr>
<tr>
<td>tewyon plate</td>
<td>1</td>
</tr>
<tr>
<td>a beame scales and triangles and</td>
<td></td>
</tr>
<tr>
<td>1000 pounds of rawe iron</td>
<td></td>
</tr>
<tr>
<td>for a weight</td>
<td></td>
</tr>
</tbody>
</table>

The repaire of the said fornace (according to an estimate thereof made) will cost about one hundred and thirtie pounds.

LYDBROOKE FORGE, consistinge of

One hammer and anvill, one chaferie, and two fineryes and 3 paire of bellowes furnished and workinge.

The house 42 foot longe, 32 foot broad covered with boards, built about 4 yeares since, in repaire.

The great hammer beame with the wheele, with 13 yron hoops, 2 great gudgeons and brasses of about 3c of cast iron and 2 yron hoops about the anvill blocke.

1 B: through. 2 B: floodgate. 3 B: approved [sic].

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Inventory of the Royal Ironworks in the Forest of Dean, 1635

On the 2 fynerie beames 9 hoopes, 4 gudgeons and 4 brasses cast iron. On the chaferye beame, 4 hoops, 2 gudgeons and 2 brasses of cast iron.

In the chimneys 3 chimney bars of cast iron and 3 morris bars.

One hurst 2 boyts of cast iron 1 bray, 1 sett of hurst wedges and 2 wedges in the hammer eye of wrought iron.

One storehouse floored and tyled built of stone 18 foot longe, 13 foot wide, and 10 foot highe in syde walls, with a paire of stayers to the chamber.

One colehouse 30 foot longe, 24 foot wide, 11 foot highe in sydewalls, covered and syded with boards, with a shut\(^1\) house for brayes on the side thereof 8 foot broad, leainge and defective.

A court paled about with 76 foot of paleinge.

An old house on one side thereof.

The dam or bay with the wast and hammer gate and ground goyte defective.

A watercourse for the wast water 180 foot longe, 4 foot square, built about 6 yeares since with two ranges of tymber with sleepers and spreaders, and plankt at the bottome, defective.

A paire of new wast gates with stems, ready framed for the forefront and not set up.

One hammer mans house built about one yeare since of tymber with a stone chimney, 20 foot longe, 16 foot broad and 8 foot highe in sydewall.

<table>
<thead>
<tr>
<th>Chaferie</th>
<th>Implements in Lydbrooke forge</th>
</tr>
</thead>
<tbody>
<tr>
<td>plates</td>
<td>5</td>
</tr>
<tr>
<td>teweiron</td>
<td>1</td>
</tr>
<tr>
<td>ringer</td>
<td>1</td>
</tr>
<tr>
<td>furgon</td>
<td>1</td>
</tr>
<tr>
<td>quase</td>
<td>1</td>
</tr>
<tr>
<td>iron dish</td>
<td>1</td>
</tr>
<tr>
<td>2 fineryes(^2)</td>
<td></td>
</tr>
<tr>
<td>plates</td>
<td>10</td>
</tr>
<tr>
<td>ringers</td>
<td>2</td>
</tr>
<tr>
<td>furgons</td>
<td>2</td>
</tr>
<tr>
<td>teweirons</td>
<td>2</td>
</tr>
<tr>
<td>quasses</td>
<td>2</td>
</tr>
<tr>
<td>iron dishes</td>
<td>2</td>
</tr>
<tr>
<td>clams</td>
<td>2</td>
</tr>
<tr>
<td>an iron beame with scales and chayns, and c w(eight) of cast iron</td>
<td>a new hammer beame readye squared neere at hand.</td>
</tr>
</tbody>
</table>

The 2 fynerie wheeles, the chaferye wheele, the hammer beame, one of the fynerie beameis, the wast hutch, the juttie of the bay, the trowes and penstocks, the cole house and one workmans house are in decay, and the repaire thereof will cost (accordinge to an estimate made thereof) about fortie pounds.

PARK END FORGE consistinge of two hammers, 3 fynerie and 1 chaferie which were generally repayed and parte new made about 2 yeares since.

The lower part of the bay 120 foot longe 12 foot highe, made of tymber with sylls, laces, and posts, the front of the bay where the water is lead to the forge, built of stone with 2 draweinge gates.

\(^1\) B: shutte.
\(^2\) B: fyner.
Inventory of the Royal Ironworks in the Forest of Dean, 1635

A floodgate¹ of 6 sluices in the bay 44 foot longe and 22 foot broad strongly tymbred, and built on each side with a stone wall of 3 foot highe above the apron and 3 foote thicke, and aproned² with planke, 160 foot belowe the sluces.

A storehouse for iron 24 foot longe 18 foot broad and 13 foot highe in sydewalls, whereof 3 foot of good stone-worke, built with tymbre and tyled, with a convenient room over it and a pair of outside stayers leadinge thereto.

One faire colehouse 62 foot longe, 29 foot broad, and 17 foot high in sydewalls whereof 5 foot stoneworke and 12 foot tymbre, 5 bayes, covered with boards, and 2 great pair of stayers unto it, built about 3 yeres since.

One coleyard inclosed within a wall 50 foot in circuit and 8 foot highe, with a great doore and hinges.

One old colehouse adjoyninge.

One house built of stone for the colekeeper 23 foot longe and 17 foot broad, tyled, and conteyns 4 roomes.

One house built for the fyner 16 foot longe 15 foot broad and covered with boards.

One house for the hammerman lately repaired.

Two cottages enjoyed by the fyners.

One little house adjoyninge to the forge for the carpenter to worke in.

Implementes in Parke-end forge.

Forgeing hammer
hoops on the hammer
beame 13
gudgeons 2
brasses 2
great hamer 1
anvil 1
hurst, and sett of hurst wedges 1
Shinglinge hammer
on the beame thereof 10 iron hoops and all things else as the forgeinge hammer hath.

Chaferie
plates 5
fixt morris plate of raw iron 1
morris bar of wrought iron 1
teewyron 1
plates of cast iron over the teewyron 2
fixt pig of iron over teewyron 1
hoops on the chaferie wheele 4
gudgeons and brasses 2
brasse-iron to keep downe the shaft of the wheele sledge 1
shovel 1
mandrill 1

The Upper Finerie
pair of belloewes furnished 1

boytes 2
bray 1
great wedges in the hammer eye 2
hoops on the anvil block 2
pair of chafery bellowes furnished 1
hammer bit 1
hammer eye 1
pair of great tongs 1
pair of shinglinge tongs 7
ringer 1
furgon 1
handhammer 1
clam 4
iron dishe 1
quasse 1
loop plate of about 3 cwt. 1
cold chissels 2
water trowes and anvill block.

loope plate 1
tewyron 1

¹ B: floodgate. ² B: approved [sic].
Inventory of the Royal Ironworks in the Forest of Dean, 1695

hoopes on the wheele 1
  shaft 4
  gudgeons & brasses 2
  plates 5
  chimney plate of 1 cast
    iron 1
    morris barr 1
    pair of shinglins tongs 1
    pair of great tongs, or maudlins 2
    iron beame scales and hookes and 2 c. of cast
    iron for a waights.

The 2 lower fyneries have implements according to the upper fynerye. The chaferye wheele, the front of the bay and some earth worke in the bay defective, the repaire whereof (according to an estimate thereof) will cost about five and twentye pounds.

WHEATCROFT FORGE. 70 foot longe and 28 foot broad consists of two hammers, one chaferie and 3 fyneries, built from the ground about 6 years since, and the lower parte thereof being burnt, rebuilt about three yeares since, in repaire and workeinge.

The bay thereof 2 460 foot longe, 26 foot broad between the stone walls which are 5 foot and an halfe in thickness at the topps and about 13 foot and halfe highe about the middle and generally 8 foot and halfe highe above the grounde.

In the bay 2 sluces or hammer gates, built with stone with 2 paire of tymber sluces to the same.

And one greate fludgate of 6 gates 37 foot longe 25 foot broad strongly built of tymber, aproned 3 with planke and double planked on the sides, with a horse bridge made over it.

One watercourse of tymber 143 foot longe 10 foot broad and 5 foot deep, ventinge the water from the forge, planked on each side with sleepers at the bottom and spreaders at the top.

One storehouse 30 foot longe 16 foot and halfe 4 broad 9 foot highe in sydewalls, covered with boards.

One great colehouse 58 foot longe 28 foot brode 17 foot highe in sydewalls whereof 5 foot from the ground built of stone, all the rest of tymber, covered with tyle, with 3 great doores and 2 paire of stayres on the outside thereof.

One other storehouse 15 foot square uncovered.

One house 2 storeys highe 34 foot longe, 17 foot broad the pine ends thereof stone, the rest tymber, tyled over.

One house for the clarke, built of tymber 2 storeys highe 24 foot longe and 15 foot broad, with 3 dormers, with a garden and a courte paled about.

One fyners house adioyninge.

Three other fyners houses thatched.

The implements and furniture of this forge, accordinge to the forge at Parke end.

The bay, the wheeles, plummer blocke, hutches and some other parts thereof are defective, the repaire whereof (according to an estimate thereof) will cost about thirtie pounds.

1 B: & [sic].
2 B: quasse.
3 B: approved [sic].
4 B: a halfe.
BRADLEY FORGE. 70 foot longe and 31 foot broad consistinge of two hammers, three syneryes and one chaferie, built from the ground about 6 yeares since, and now workeinge. And for the parts thereof and the implements used therewith, is agreeable to the forge at the Parke end.

The dam is 183 foot longe, 20 foot broad between the stonewalls, which are 3 foot thicke on the top and 18 foot highe about the middle of the dam.

In the dam a fludgate1 of 4 gates, 20 foot longe 18 foot broad aproned2 and covered with planke for a bridge, with a3 carriage for the water 76 foot longe 18 foot broad walled on each side and piched with stone in the bottom with a fall at the end thereof made of tymber 36 foot longe and 18 foot broad.

The rest of the sluices and huches, as in the forge at the Park end.

One colehouse of 6 bay, of stone buildinge and tyled, 60 foot longe 28 foot broad and 16 foot highe in sydewalls, without doores, but hath a court 35 foot longe 26 foot broad walled about with a wall 7 foot highe with doores.

The clarkes house built of stone, 3 stories highe and tyled, is 56 foot longe, 20 foot broad with a crosse buildinge 19 foot square.

Foure workmens cottages thatched.

There are 2 new hammer beames readie made, lyeinge under the wall of the colehouse courte.

The wheeles, shafts, shinglinge hammer beame, tyleinge of the colehouse, huches and plumer blocks, scales and bellowes defective, the repaire whereof will cost (accordinge to an estimate thereof) about one hundred pound(es).

SOWDLEY FORGE.4 42 foot longe, and 30 foot broad, consistinge of one hammer and anvill, one chaferye and two syneryes new built in the place of a decayed forge there, about two yeares since. The parts and implements whereof are accordinge to the forge at Lydbrooke.

One store house adjoyninge to the forge 16 foot square with a roome over it, built of tymber and covered with boards.

One cole house 36 foot longe, 27 foot broad, 9 foot highe in the side walls, with a dormer, and covered with boards.

In the dam a new fludgate in the place of one that the fluids carried away, of 6 gates, 94 foot longe and 10 foot broad, aproned5 with planke and cheeked with stone.

The wheeles groundsills troues penstocks and some other parts thereof defective, and the repaire thereof (accordinge to an estimate made thereof) will cost about three score pounds.

Memorandum that the now farmers Sr. Baynehem Throckmorton and his partners are not to be charged by this inventory with anie of the implements of Whyte Croft double forge and Bradley double forge which are not fixed to the freehold, bycause those two forges were erected and made by the late farmers Sr. Basill Brooke and Mr. Mynn, of whome the newe farmers are to buye all the moveable implements and furniture of the same as they shalbe apprised and valued indifferently betwene them.

C. Harbord6

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1 B: floodgate.
2 B: approved [sic].
3 In B the whole section concerning Soudley forge is placed between the sections on Parkend and Whitecroft forges.
4 B: approved [sic].
5 Omitted in B.
6 The signature is omitted in B and replaced by: per bre de privato sigillo, etc.
APPENDIX XIII

Description of a Seventeenth-century Bloomery and the Process Involved, by John Sturdie of Lancashire, Thurnham, September 25 1675

It (i.e. the furnace) is very much like a common blacksmith's, viz., a plain open hearth or bottom without any enclosing walls, only where the nose of the bellows come in through a wall there is a hollow place (which they call the furnace) made of iron plates, as is also that part of the hearth next adjoining. This hollow place they fill and up-heap with charcoal, and lay the oar (broken small) all round about the charcoal upon the flat hearth, to bake it, as it were, or neal and thrust it in by little and little into the hollow, where it is melted by the blast. The glassie scoriae run very thin, but the metal is never in a perfect fusion, but settles as it were in a clod, that they take out with tongs, and turn it under great hammers, which at the same time beat off (especially at first taking out of the furnace) a deal of courser scoriae, and form it after several heats into bars. They use no lime-stone to promote the flux, for that I enquired particularly.

APPENDIX XIV

Furnaces and Furnace Practice in England in the late Seventeenth Century

A. In the Weald of Sussex, Kent, and Surrey, in 1674


After it (i.e. the ore) is burnt, they beat it into small pieces with an iron sledge, and then put it into the furnace (which is before charged with coles), casting it upon the top of the coles, where it melts and falls into the hearth, in the space of about twelve hours, more or less, and then it runs into a sow. The hearth or botomme of the furnace is made of a sandstone, and the sides round to the height of a yard, or thereabout: the rest of the furnace is lined up to the top with brick.

When they begin upon a new furnace, they put fire for a day or two before they begin to blow.

Then they blow gently and increase by degrees till they come to the height in ten weeks or more.

Every six days they call a Founday, in which space they make 8 tun of iron, if you divide the whole summ of iron made by the foundays; for at first they make less in a founday, at last more.

The hearth by the force of the fire, continually blown, grows wide and wider, so that if at first it contains so much as will make a sow of 600 or 700 pound weight; at last it will contain as much as will make a sow of 2000 lb. The lesser pieces, of one thousand pounds, or under, they call Pigs.

Of 24 loads of coals, they expect 8 tun of iron, to every load of coals, which consists of 11 quarters, they put a load of mine, which contains 18 bushels.

A hearth ordinarily, if made of good stone, will last 40 foundays, that is 40 weeks, during which time the fire is never let go out. They never blow twice upon one hearth, though they go upon it not above five or six foundays.

B. In the Forest of Dean, Gloucestershire, in 1678

Furnaces and Furnace Practice in the late Seventeenth Century


From hence (i.e. from the kilns used for calcining or burning the ore) they carry it to their Furnaces, which are built of brick and stone, ab. 24 foot square on the outside, and near 30 f. in height, within, and not above 8 or 10 ft. over where it is widest, which is about in the middle, the top and bottom having a narrower compass, much like the shape of an egg, as in the Figure 4, A the Tunnel, C the furnace, B the Mouth (facing p. 923).

Behind the furnace are placed 2 huge pairs of bellows, whose noses meet at a little hole nr. the bottom. These are compressed together by certain buttons placed on the Axis of a very large wheel, which is turned by water in the manner of an overshot wheel. As soon as these buttons are slid off, the bellows are raised again by the counterpoise of weights, whereby they are made to play alternately, the one giving its blast all the time the other is rising.

At first the Furnaces are filled with ore and cinder intermixt with fuel, which in these works is always of charcoal, laying them hollow at the bottom, that they may more easily take fire. But after they are once kindled, the materials run together in a hard cake or lump which is sustained by the fashion of the furnace, and through this the metal, as it melts, trickles down into the receivers which are placed at the bottom, where there is a passage
Furnaces and Furnace Practice in the late Seventeenth Century

open, by which they take away the scum or Dross, and let out the metal, as they see occasion. Before the mouth of the Furnace lies a great bed of sand, wherein they make furrows of the shape into which they intend to cast the metal. Into these when the receivers are full they let in their metal, which is made so very fluid by the violence of the fire, that it not only runs to a considerable distance but stands afterwards boiling for a good while. After these furnaces are once at work, they keep them constantly employed for many months together, never suffering the fire to slacken night or day, but still supplying the waste of the fuel, and other materials, with fresh, poured in at the top.

Several attempts have been made to bring in the use of sea-coal in these works, instead of charcoal, the former being to be had at any easy rate, the latter not without great expense; but hitherto they have proved ineffectual. The workmen finding by experience, that a sea-coal fire, how vehement soever, will not penetrate the most fixed parts of the ore, by which means they leave much of the metal behind them unmelted.

(followed by a description of the process conducted in the forge.)

For several purposes as for the Backs of Chimneys, Hearths of Ovens, or the like they have a sort of cast-iron, which they take out of the receivers of the Furnace as soon as it is melted, in great ladles, and pour it into moulds of fine sand; but this sort of iron is very brittle, that being heated with one blow of a hammer it breaks all to pieces.

C. In Staffordshire, in 1686

Description by Robert Plot, The Natural History of Staffordshire, p. 163, Oxford, 1686.


In melting of Iron-ore some have great regard to the make of the furnace, and placing of the bellows; which that the Reader may better understand, He must be informed that the hearth of the furnace into which the ore and coal fall, is ordinarily built square, the sides descending obliquely and drawing near to one another toward the bottom, like the Hopper of a Mill: where these oblique walls terminat, which they term the boshes, there are joined four other stones, but these are commonly set perpendicular, and reach to the bottom stone, making the perpendicular square that receives the Metall; which four walls have the following names; that next the bellows, the tuarn or tuiron wall; that against it, the windwall or spirit-plate, that where the Metall comes out, the Timp or fore plate.

The subsequent passages in which Plot speaks of different inclinations given to the walls and their effect upon the iron, are literally copied from Dud Dudley, Metallum Martis, p. 42, first edition, London, 1665, but by Plot erroneously applied to the hearth of the furnace instead of that of the finery, as Dudley did. Then he goes on:

Nor is the ordering of the bellows of less concern, which have usually their entrance into the furnace between the bottom of the Hopper or boshes, and the bottom stone, and are placed nearer or farther off according as the Ore and Metall require.
APPENDIX XV
Hearths of Finery and Chafery in Seventeenth-century England (reconstructed)

A. Finery Hearth
(a) bottom plate
(b) fore plate
(c) slag hole
(d) tuyere plate
(e) tuyere

(b) fore plate
(g) fore spirit plate
(h) work plate
(i) bellows
(k) aperture for pig

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Hearths of Finery and Chafery in Seventeenth-century England

B. Chafery Hearth

(a) bottom plate
(b) fore plate
(c) slag hole
(d) tuyere plate
(e) tuyere
(f) hare plate
(g) fore spirit plate
(k) plate lying on the fore spirit
APPENDIX XVI

Hanbury's Observations on the Making of Iron at Pontypool and Llanelly

1704 (with additions until 1708).
Manuscript at Pontypool Public Library.

By the numbers of the sections which are not consecutive the present manuscript appears to have been abstracted from an earlier one. Apparently it was made when John Hanbury, later known as Major Hanbury, inherited the works from his father Capel Hanbury who died in 1704.

(1)

An Account of the Dementions of the Furnace hearths as usually made by Richard Hawkins (compare illustration in Fig. 32).

<table>
<thead>
<tr>
<th>Foot</th>
<th>Inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5 6</td>
</tr>
<tr>
<td>2</td>
<td>3 6</td>
</tr>
<tr>
<td>3</td>
<td>4 6</td>
</tr>
<tr>
<td>4</td>
<td>3 6</td>
</tr>
<tr>
<td>5</td>
<td>4 6</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>2 4</td>
</tr>
<tr>
<td>8</td>
<td>2 7</td>
</tr>
<tr>
<td>9</td>
<td>1 6</td>
</tr>
<tr>
<td>10</td>
<td>1 10</td>
</tr>
<tr>
<td>11</td>
<td>13 6</td>
</tr>
<tr>
<td>12</td>
<td>4 6</td>
</tr>
</tbody>
</table>

1 Corrected from 4.
2 'lower' is added above the line.
3 Scuncheon, from old French 'escoinson', is the inner edge of the stones in which the tumpstone is set.
4 No. 10 is omitted.
5 The 'c' in scale is added in pencil. By scale is meant the degree at which the bottom stone sloped from the back to the front.

2F—H.L.S. 423
Hanbury's Observations on the Making of Iron at Pontypool

(4)

Pontpoole Furnace.

Observations on the Furnace at P(ont)pool.

That the pig iron these several last blasts has bin made at Pontpoole at about 18 s. to the tun & this last blast at less.

That 1200 long cords of wood is too full an allowance to make 600 lo(ad) of cole of the larg(e)st sacking, but if any of the computations are too low, the allowance of two long cord to make a load of cole will more than pay for.

That the limestone being my own & within half a mile of the furnace might be had under 12d. per t(un).

600 lo(ad) of cole cost £890, is £1 9s. 6d. per load.

400 tuns of pigges cost £1465, is 3: 13: 3 per tun.

If there were kilns built at the distant myneworkes where now carriage is 6s. & 6s.-& 6d. and the myne burnt & broke there I me confident it might be carried 2s. per doz(en) cheaper than it is now for at least 600 doz. per ann(um), but a place must be built at the furnace to keep it very drye, it might be burnt with stone cole which would over pay the charge of the kilns and work men.

(5)

Charge of making 400 t(uns) of cast iron yearly at Pontpoole

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long cords of wood 1200 at 7 s. per cord</td>
<td>420</td>
</tr>
<tr>
<td>Cutting the said wood at 3 s.</td>
<td>180</td>
</tr>
<tr>
<td>Coaling 600 lo. of cole made of that wood at 3s.</td>
<td>90</td>
</tr>
<tr>
<td>Carrying the said cole at 6s.</td>
<td>180</td>
</tr>
<tr>
<td>Sacking etc.</td>
<td>20</td>
</tr>
<tr>
<td>Myne &amp; cinders at an avarage 20s. per t.</td>
<td>400</td>
</tr>
<tr>
<td>Limestone 12s &amp; sand 12s</td>
<td>40</td>
</tr>
<tr>
<td>Hearth, bellows &amp; labour</td>
<td>35</td>
</tr>
<tr>
<td>Workemens wages at 3s pr t.</td>
<td>60</td>
</tr>
</tbody>
</table>

£ 3 11 3

per t(un)

1425

400 t. of pigs at 6£ per t(un) 2400

(7)

The furnace should be kept very drye after the fire is out, we usually thatch the top for about 40s. cost which does well but I believe the very best way would be to build a brick Cupola with large doores to let in light & when the blast is over to keep a pritty constant fire in the hearth place, this I designe to doe.

We have tryd our stampers to break our myne they are too light, if stampers could be set up to break it very well & to dispatch a quantity I think would be of good advantage, however it will pay very well to have it broke with hands.

Cinders from the finery's of all sorts doe very well and allowing three doz(en) to the tun it brought the yeild of myne from 32 bushels to the tun to 28. The miners gain by it. The stampers break cinders very well, they are usually washt when stamped, we doe not dry them if we did I think they would spend much better.

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Hanbury's Observations on the Making of Iron at Pontypool

If the myne could be broke much smaller I suppose the best way would be to charge but four baskets of cole at a time, least the fire should be clog(e)d by the smallness of the mine, would doe very well to trye it.

(8)

<table>
<thead>
<tr>
<th>Description</th>
<th>Per week</th>
</tr>
</thead>
<tbody>
<tr>
<td>The usual charge at furnace.</td>
<td></td>
</tr>
<tr>
<td>Two keepers</td>
<td>8s. each</td>
</tr>
<tr>
<td>Two fillers</td>
<td></td>
</tr>
<tr>
<td>Filling the kilns drawn(1) &amp;</td>
<td></td>
</tr>
<tr>
<td>burning myne</td>
<td></td>
</tr>
<tr>
<td>For 4 men breaking myne</td>
<td>4s. each</td>
</tr>
<tr>
<td>Stocktaker</td>
<td></td>
</tr>
</tbody>
</table>

2: 16

(9)

We used formerly to charge our furnaces five foot deep which would take 13 baskets of cole at each charge, but for some years last we charge with 8 baskets & but 3 foot 2 inches deep, the 8 baskets are not above 2 sacks & ½. This last way does much better for yeild, the 8 baskets usually bears from 20 to 24 boshels of myne and cinder which commonly produces at 8 charges 25 c. tops. of iron which is above 3 c. to two sacks + ½ of coles. I cannot but think that we should doe yet better if we char(ge)d but 2 foot & ½ deep at 6 baskets of cole.

May 16, 1704. Weigh(e)d one bushel of myne unburnt at Lanelly & a bushel burnt & the difference in weight was 50, the bushel of raw myne weigh(e)d 4c. 3qr. & therefore when burnt was 4c. 3qr. - 50 lbs. = 4c. 1 qr. 6 lb. for the weight of a bushel of burnt myne.

John Waters says there goes about 2 sacks of cole to burne as much myne as will make a tun of iron.

1707 Agreed with Daniel David that he should bring in his myne ready burnt & to receive nine shillings per dozen, he did soe one part of the blast & burnt it very well, but doe better this year 1708, we are assured that 2 doz. soe burnt will make a tun of iron, the pigs soe made make good iron.

(11)

Oct. 6, 1708 began to blow at Neath or Melin Court furnace (God Prosper) the hearth made with small stone such as we make the boshes with. Mem(ornandum) the hearth was made half an inch wider than usual with great stone

(16)

Pontpoole Forges.

If any of the computations for making bar iron are short the two long cord to a load will make it good which is a fourth of a long cord too much in a load which is over in the t(un) 75 lb.

The yield of two load of cole & braises to make a tun of iron must be perform(e)d with the very best manage, the anchories must be made at one forge & drawn out at another.
Hanbury's Observations on the Making of Iron at Pontypool

Note that when braises may be all spent at the furnace & the finerys we can draw iron out very well with stone cole at about 3s. per t(un) charg(e), about 60 will be lost in the loops but at some charge those loopes may be sunk to stampers or large furnace bars.

The stone cole comes from Blain Avon at near 7s. per doz(en). 1 doz(en) will draw out near 21 tuns of bars.

(17)

The charge of making 300 t(un) of bar iron yearly at the forges at Pontpoole.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pig iron 400 t(un) at 6s. per t(un)</td>
<td>2400</td>
</tr>
<tr>
<td>Wood 1200 long cords at 7s. per c(ord.)</td>
<td>420</td>
</tr>
<tr>
<td>Cutting ditto &amp; cording at 3s. per c.</td>
<td>180</td>
</tr>
<tr>
<td>Workmens wages with their fire at 20s. per t.</td>
<td>300</td>
</tr>
<tr>
<td>Clerks wages</td>
<td>130</td>
</tr>
<tr>
<td>Stocktakers, carpenters &amp; rents</td>
<td>100</td>
</tr>
<tr>
<td>Hammer, anviles, leather &amp; grease</td>
<td>50</td>
</tr>
<tr>
<td>Car(riage) of pigs at 15d. per t.</td>
<td>25</td>
</tr>
<tr>
<td>Timber 10s. Labour 20s. Smith 20s.</td>
<td>50</td>
</tr>
<tr>
<td>Sacking</td>
<td>20</td>
</tr>
<tr>
<td>Coaling 600 load at 3s. per l(oad)</td>
<td>90</td>
</tr>
<tr>
<td>Car(riage) ditto at 5s. 6d. per l(oad)</td>
<td>165</td>
</tr>
</tbody>
</table>

This charge is at the rate of 13s. 2s. per t(un)
Bar iron 300 t. at 15s. per t.          4500

(28)

Lanelthy Furnace

Lanelthy furnace hath bin almost ruined for want of being covered from wet and lying two years and more at a time without fire.
The kilns and colehous and myne places are now put into very convenient order.
The colehous holds 240 load and more; the whole cost near 300£, but there must be a brick cupola built there at the end of the next blast, she allways goes well when warmed.
Mem(orandum) that the price of woods is put at the highest soe is the price of car(riage) and when the car. is 8s. the wood price is less always.
The allowance of 2 long cords to make a load of cole is at the largest and a fourth of a long cord may be well saved out of every 2 cord which is 2s. 7½d. soe that if they should spend 20 s(ack)s to a tun it might be well don at 3.13.8d per ton.

1 Corrected from 3.
2 The sums paid to workmen have been corrected afterwards but evidently by the same writer from 100 to 300, clerk's wages from 100 to 130 and the total from 3,700 to 3,930.
Hanbury's Observations on the Making of Iron at Pontypool

(29)

Observations on the making of cast iron at Lanelthwy furnace the charge as under of making 300 tons yearly.

<table>
<thead>
<tr>
<th>Item</th>
<th>£</th>
</tr>
</thead>
<tbody>
<tr>
<td>900 long cords of wood at 7s per cord</td>
<td>315</td>
</tr>
<tr>
<td>Cutting ditt(o) at 3s 6d</td>
<td>157 10</td>
</tr>
<tr>
<td>450 load of Cole coling at 3s 4d</td>
<td>75</td>
</tr>
<tr>
<td>Carriage ditt(o) at 8s</td>
<td>180</td>
</tr>
<tr>
<td>Sacking and hurdles</td>
<td>20</td>
</tr>
<tr>
<td>Myne at an average at 16s 6d per tun</td>
<td>247 10</td>
</tr>
<tr>
<td>Limestone 12d &amp; sand 8d</td>
<td>25</td>
</tr>
<tr>
<td>Hearth and bellows</td>
<td>25</td>
</tr>
<tr>
<td>Workmen and Labour at 4s</td>
<td>60</td>
</tr>
</tbody>
</table>

3 13 8d. per ton 1105
300 t. of pig iron at 6s per t. 1800

Load of Cole 450 cost 747s. 10d. which is at the rate of £1 13s. per load.
The pigs cost in cole per t. 2 9 10
Myne per t. 16 6
Limestone and sand 1 8
Bellows and hearth 1 8
Workmen and labour 4 0

3 13 8d

(31)

For the future I think of making about 300 tun of pigs yearly at Lanelthwy & I am of opinion the best way would be to blow every year.

I think the proper time would be to begin constantly in the beginning of September & 300 tun would be cast in January at farthest, soe there would be all the spring to fill the house to keep till winter & from Sept. to the later end of Novbr. to bring present stock.

There has been great quantitij of dust myne washed (which was thrown by for 20 years) & spent to great advantage, some is left still.

Mem. that Mr. Lewis told me that one time in a blast they spent 9 or 10 boshes of small myne to a charge, which much bettered the yeild of cole and at the close of the blast they for 2 or 3 sowses the spent all small mine washed & the furnace rose from 24 boshes to 33 in burden & made extraordinary yeild.

Surely 'twould answer very well to have all the myne soe broke & washed & dried; it shall be tryd.

Mr. Lewis once at the close of a blast spent a fourth part of stonecole, it made the cinder run black the pigs were layd by for 2 year & then made good iron.

(33)

An account of the price of myne I had from Mr. Lewis 1705.
The near worke cost per tun 15s. But the best part of that myne is Dan Davids worke which now goes to Pontpoole.
The greatest worke which is Clydach cost 5s. ye raising & 12s. car(iage) per tun— — — 17s.
Hanbury's Observations on the Making of Iron at Pontypool

Some of the farther workes that produce very good myne comes at 15d. per doz. raising & 5s. car. which at 2 doz. 8 bush per tun is — 16(s.) 8d.

Note that Clydach myne is the most cold-short wee have. I suppose best to have less of that & more of that good myne of 15s. & 16s. 8d. per tun which would reduce the myne in general under 16 & 6 per tun. — The last blast much bad iron.

They have not yet spent any quantity of forge cinders at Lanelthy furnace, this blast they have good quantity which I suppose will better the iron & the yeild.

Mem(orandum) that Mr. Lewis once blew the furnace out and as soon as ever the hearth was coole he found that the wind wall was quite worn away, he having then 2 or 300 t. more to blow he did not put in a new hearth but mended the wind wall with small stone at about ten shillings charge and blew agen. Note the furnace came immediately to her rate and went as well as ever she was known to goe.

LANELTHY FORGE

Observations on the making of bar iron at Lanelthy forge. If the computation of labour or materials is in anything the allowance of two long cords to mak a load of cole is a fourth of a cord to(o) much which is 1s. 5d. in the whole which will fully answer in any other article. The allowance of 30 s(ack)s of braises and cole to make a ton is full enough. I suppose it might be done under if the right way were taken as thus—the finers to work from Tuesday till Saturnday morne and then the hammerman to draw it out Saturnday, Monday and Monday night to have the hammer to himself which must save cole. But the only way to go on at a certainty would be to have a place walled for the pigs and the pigs and anchonies to be delivered by weight and the cole by baskets and to have a weekly account constantly kept which should be.

Charge of making bar iron at Lanelthy forge at 110 tons pr. ann.

<table>
<thead>
<tr>
<th>Item</th>
<th>£</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pigs 148 t. 10c. at 6£ per ton</td>
<td>891</td>
</tr>
<tr>
<td>Long cords of wood 500 at 7s per cord</td>
<td>175</td>
</tr>
<tr>
<td>Cutting ditto and cording at 3s. 6d.</td>
<td>87 10</td>
</tr>
<tr>
<td>Coaling 250 load at 3s. &amp; 4d.</td>
<td>49 13 4</td>
</tr>
<tr>
<td>Carriage ditto at</td>
<td>100</td>
</tr>
<tr>
<td>Workmen including their cole at 20s. per t.</td>
<td>100</td>
</tr>
<tr>
<td>Wages and labour &amp; materials at 20s. per t.</td>
<td>100</td>
</tr>
</tbody>
</table>

1494 03 4d

Bar iron 110 ton at 15£ 10s per ton. 1705
Hanbury's Observations on the Making of Iron at Pontypool

(48)

Pontpoole Plate

I think the computation on the other side is large enough, if short in any thing 'tis in the allowance for wast of 2 c. to the tun—but then the parings & ends of the bars are worked up aven which Ime sure will reduce it to the allowance,

The plate is valued at 27£ per t. at the mill which at an average is the lowest for I sell to Mr. Crowley, the cheapest I sell viz. d(eliver)e'd at Gloster or Bristol singles at 26£ 10s. & doubles at 28£ 10s. to Mr. Hearn, Mr. Worrall etc., at 30£.

Mr. Bags sells for me in London at 33s. the singles & 35s. the doubles—the thinnest doubles at 37 & very thick singles at 37—charge car(riage) to London 3£ 10s., to Mr. Baggs 20s. & petty charges, rent etc. 10s., total 5£.

We now make the broad plate at the Upper Mill but there is little or noe water spare in the summer and in ye winter can scarce be spared from slitting.

(49)

Charge of making rowed plate at Pontpoole at 60£ per ann(um)

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barr iron 66t. at 15£ 10s. per t.</td>
<td>1023</td>
</tr>
<tr>
<td>To the maker for rowing per t. 3£</td>
<td>180</td>
</tr>
<tr>
<td>Coles 5s. rows steel &amp; sallery 15s. tot(al)</td>
<td>60</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1263</strong></td>
</tr>
</tbody>
</table>

Discharge by 60t. of plate at 27£ per t.

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron 2c. allowed for wast, 22c. at 15s. 6d. per c.</td>
<td>17 1</td>
</tr>
<tr>
<td>To the maker 3£ per t. &amp; 10£ per ann(um)</td>
<td>3 3 4</td>
</tr>
<tr>
<td>Coles 5s. per t., rows &amp; steel 11s. 8d. tot(al)</td>
<td>16 8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>21 1 0</strong></td>
</tr>
</tbody>
</table>

(51)

I conceive the most profitable way of making of plate for the future would bee to have the engine for broad plate brought down to the Lower Mill and there to work double hand day and night which would make all sorts of plate and I suppose very near 2 t. per weeke, especially since there is so much demand for thick sorts. I suppose 5 men at most would carry it on double hand which might be had under 40 s. per week and the plate would come to 5£ ye week.

I pay 3£ per t. for the working of plate which is a fair rate for doubles but 2£ or 2£ 10 is enough for singles especially since soe much of that sort is made.

(58)

Pontpoole Rods & Hoopes

There is noe manner of profit by the rod mill but only the advantage of making the barr iron soe gross which 'tis recound that tis 20s. per t. better to make mill iron then merchant which is the very best can be said of the rod mill.

There is about 2£ 10s. gaine in a tun of hoopes but we doe not make above 10 t. per ann. & the slitter does not much care for it at 20s. per t.
Hanbury’s Observations on the Making of Iron at Pontypool

(59)

Charge of making a ton of rods

<table>
<thead>
<tr>
<th></th>
<th>£</th>
<th>s</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill bar iron 1 t.  oc. 3q</td>
<td>15</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>quarters at 15£ per t.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To the slitter</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>For stonecole</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>For rowles &amp; steel etc.</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

A tun of rods at ye mill worth

16 10

Charge to make a tun of hoopes

<table>
<thead>
<tr>
<th></th>
<th>£</th>
<th>s</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill iron 1t. 2c. at 15£</td>
<td>16</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>per t.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To the slitter</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>For coles</td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

A tun of hoopes at the mill worth

20

(67)

Observations on woods in Monmouthshire

1705. The price is risen from 4 & 5s. the long cord to 7s. & 8s. the cord, the old woods are most spent but people are generally more careful of their copise since the encouragement of price, we usually cut at 16 or 17 years growth but if mountaine ground & the wood beech than will take 20 years or more.

A well grown copise will yeild 12 long cords of an acre which if cut evry 16 years will make the lands worth 5s the acre per ann(um).

Certainly if all the strong and course land in the mountaines were turned to bare wood 'twould be a certaine improvement.

There are several pieces of ground inclosed that are not now worth 12d. per acre—supose an acre were set with wood it would rise to 5s, per acre & the charge would be as follows—2000 birch quick at 6d. per c [hundred], the getting & the setting them 10s, & if any part wants to be fenced it might be don in most places for 3s. evry 7 yards & 5 foot high—

(69)

<table>
<thead>
<tr>
<th></th>
<th>foot</th>
<th>inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Welsh measure for wood is</td>
<td>9</td>
<td>—</td>
</tr>
<tr>
<td>long</td>
<td></td>
<td></td>
</tr>
<tr>
<td>broad</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>high</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>which contains</td>
<td>175</td>
<td>6</td>
</tr>
<tr>
<td>the Statute cord contains</td>
<td>128</td>
<td>—</td>
</tr>
</tbody>
</table>

430
Description of Furnace and Smelting at Leighton, in Yealand Redman, Lancashire.

No date (between 1722 and 1740)

Although the author has copiously copied from H. Powle's description of ironworking in the Forest of Dean (Phil. Tr., vol. xii, p. 933), and occasionally from Plot, he has supplied many valuable details.

The description was discovered in a MS History of Warton Parish, compiled by John Lucas in the early eighteenth century, and edited by J. Rawlinson Ford, Kendal, 1931. Published in VCH, Lancashire, vol. ii, pp. 136 et seq. (erroneously ascribed to a 'bloomery' at Brackenthwaite).

But to come to a particular Description of this Furnace. It is built like most others, against the Side of an Hill, in a square Form, the Sides descending obliquely about Six Yards, and drawing nearer one another towards the Bottom like the Hopper of a Mill. These oblique Walls terminate at the Top of a perpendicular Square called the Hearth whose Side is about 4½ Feet which is lined with the best Fire Stone to take off the Force of the Fire from the Walls, and to hold the fluid Metal which drops into it as it melts. The Top of the Furnace is covered with a large thick Iron Plate, in the Middle of which is a Hole about ½ of a Yard square where they throw in the Fuel and Ore. When they begin to work a new Furnace, they put in Fire for two or three Days before they begin to blow, which they call Seasoning, at first they blow gently, gradually increasing till in about three Weeke. Time the Fire will be so intense that they can run a Sow and Pigs once in about twelve Hours: and after they are once kindled they are kept at Work Day and Night for many Months or Years, still supplying the Wast of the Fuel & other Materials with fresh poured in at the Top.

The Ore they use here is brought across the Bay by Coasters from Stenton in Furness, where it is found lying in the Cliffs of the Rocks of gray Limestone. The Veins are sometimes an Inch, sometimes a Foot, and sometimes three or four Yards broad, which they have followed towards the Centre of the Earth for many Fathoms. The Ore which lies at the outside of the Vein or near the Rock on either Side is hard, and that which is in the Middle is commonly soft like Clay. They are both red or else bluish, and smooth as Velvet to the Touch when broken. As for the medicinal Uses of this Ore, they use the soft sort frequently, and with great Success, for the Murrain in Cattle, and for most Diseases in Swine they give a Handfull or two in Milk.

1 'The Sides—Walls terminate', copied from Plot, p. 162.

2G—H.I.S.
When the Ore which the Workmen here commonly call the Mine, is brought to the Furnace, their first Work is to burn it in a Kiln, much after the Fashion of our ordinary Limekilns; a Thing we find practised not only in the Iron Works in Sweeden, but also in all the Mines in Hungary, whether Gold, Silver, Copper, Iron, Lead or Lapis Calaminaris. These Kilns they here fill up to the Top with Turf and Ore Stratum super Stratum, and then putting Fire to the Bottom let it burn till the Fuel be wasted, and the mere dressy Part of the Ore consumed, and the other Part rendered more soft and malleable; otherwise if it should be put into the Furnace as it comes out of the Earth, it would not melt but come away whole. Care also must be taken that it be not over much burned, for then it will loop, i.e. melt and run together in a Mass. After it is burnt they beat it into small pieces on the Rost-Hearth as the Germans call it with an Iron Sledge or large Hammer, and then cast it into the Furnace (which is before charged with a certain Quantity of Charcole and Turf) and with it a small Quantity of Limestone and old Cinders; these all run together into a hard Cake or Lump which is sustained by the Fashion of the Furnace, through the Bottom of which, the Metal as it melts by the Violence of the Blast, trickles down into the Hearth or Receiver, where there is a Passage open much like the Mouth of an Oven, by which they clear away the Scum and Dross, which they always take off from the melted Iron before they let it run.

When they find the Fuel to have subsided something more than a Yard (which they prove by an Iron Gauge or Instrument much like a Flail) which is in the Space of about an Hour, they fill the Furnace again. Their Charging here consists of a certain Quantity of very hard black Turf (the best in its Kind of any perhaps in England which is dug up in Arnset Moss, about half a Mile from them) and Charcoal, upon which they throw Four Hundred Weight of burnt Ore of different Sorts and Goodness, together with a 10th or 12th Part as much Slaken as the Germans call them, or old Cinders with they here call Forest Cinders, and the same Quantity of Limestone beaten into small Pieces, to make it melt freely and cast the Cinders.

[Followed by remarks on calcining in France.]

But if the longest and largest Experience may be allowed as Judge, we shall find Limestone pronounced the most proper Assistant in melting Iron Ore: for the Sweedes who (notwithstanding the great Quantities we make) do yet furnish us with near two thirds of the Iron wrought up and consumed in the Kingdom, besides the vast Quantity they export to other Parts of the World, have always used it, and find it so absolutely necessary that the Mine will not run to so good Advantage without it.

They have found here by Experience that Turf which is here both very good and very cheap, doth not only spare Char Coal, but makes better Iron than Charcoal alone: upon which Account it is that the Iron made at the Furnace is much preferable to that which was made some years since at Milthorpe in this Neighbourhood, where Charcoal was the only Fuel they made Use of.

The Water does not here blow the Fire by a Pair of Philosophical Bellows, as at the Brass Works of Tivoli, near Rome: but behind the Furnace are placed two huge Pair of Bellows each 7½ Yards long, and 1½ Yard broad,
Furnace and Smelting at Leighton, Lancashire

whose Noses meet at a little Hole near the Bottom of the Furnace. These\(^1\) Bellows are compressed together by certain Buttons placed in the Axis of a very large Wheel, which is turned about by Water in the Manner of an Overshot Mill. As soon as these Buttons are slid off, the Bellows are raised again by the Counterpoise of Weights, whereby they are made to play alternately, the one giving their Blast all the Time the other is rising. The Axis of this Wheel is 12 Yards long, and its Diameter is ten Yards within the Rim; so that allowing for the Thickness of the Rim, and the Depth of the Buckets, it will, I think, be found to exceed those at the great Copper Mines in Sweden whose Circumference according to Nauleys\(^2\) is but about one Hundred Foot; and to be much about the Size of that observed by Dr. Brown a considerable Depth in one of the Hungarian Mines, which being turned about by the Fall of a subterraneous Torrent moved Engines which pumped out the Waters from the Bottom of the Mine into a Cavity wherein this Wheel (whose Diameter is 12 Yards) is placed, whence it runs out at the Foot of the Mountain; but it will be found to fall short of the Size of that mentioned by Dr. Leopold, the Diameter of which he says was forty eight Foot, and the Machine it moves draws up Buckets full 800 foot.

When the Furnace is fit to run, as they term it, which is once in about 12 Hours, they make a long Furrow through the Middle of a level Bed of Sand directly before the Mouth thereof, which they call the Sow, and out of it on each Side cleaven or twelve smaller for the Pigs, and all these they make greater or lesser according to the Quantity of their Metal which is then nothing but a Torrent of liquid Fire; made so very fluid by the Violence of the Heat, that when it is let out of the Receiver or Hearth, by breaking a Lump of Clay out of a Hole at the Bottom thereof, with a long Iron Poker, it not only runs to the utmost Distance of the Furrows, but stands boiling in them for a considerable Time. Upon the Extinction of the Fire the Redness goes off and the metallic Particles coalesce and subside one upon another, and it begins to look blackish at the Top; then they break the Sow and Pigs off from one another; and the Sow into the same Lengths with the Pigs, which is now done with ease; whereas if let alone till they were quite cold, the doing of it would be much more difficult.

The Hearth grows wider by using, so that their Runnings are much larger at the latter End than at the Beginning; for the Master Founder here told me on the 12th of June 1717 that they then ran ab\(^1\) Sixteen or Seventeen Hundred Weight at a Time, and in the Year 1721, he told my Brother they then ran twenty two Hundred Weight. When they Cast Backs for Chimneys, Rollers for Gardens, Pots or Pans &c. they make Moulds of fine Sand, into which they pour the Liquid Metal with great Ladles, as they do who cast Brass or other softer Metals. But this Sort of Iron having not undergone the Preparation of the Finery and Chafery in the Forge, are so very brittle that with one Blow of a Hammer, it will break all to Pieces, especially if it be hot.

[Followed by remarks on the yield of Hungarian mines.]

By the same Reason the Mine here may also be said to be very rich, for if we compare the Chargings and Runnings in 12 Hours as above we shall find that 100 Lb. of Ore yields 40 Lb. of Iron, or upwards.

\(^1\) The two subsequent sentences are copied from Phil. Tr., vol. xii, p. 933.

\(^2\) Olaus Nauleus, Delineatio magnae fodiens Cuprimentarum, Upsaliae, 1702-03.
APPENDIX XVIII

Description of Finery and Chafery
and the Processes Involved

Undated (about 1760)

Cardiff Central Library MS 3.250, vol. iv, fols. 169–173

The forge-finery, or second process, whereby the brittle reguline cast iron is made malleable.

Finery described. The furnace in which this second process is performed, called by the workmen the finery-hearth, in its general structure resembles much that of the smith, but is not elevated above the floor more than 20 inches. The fire-place or what is properly called the hearth, is a quadrangular cavity, composed of strong plates of cast iron, about 18 inches broad, 24 inches long, and 8 inches deep, and open at the top. The tuyiron, which is an iron pipe of a peculiar form, through which the blast of the bellows is introduced to the fire) is placed in the side of the hearth, at about 6 inches from the bottom, and 9 inches from the nearer end; and a little under the level of that is a hole in the plate which forms the nearer end of the hearth and at which the workman stands, the use of which will appear hereafter. These dimensions are not to be considered as invariable; they are changed according to the peculiar disposition of the metal to be operated upon, and in the due adjustment of these does the finers art greatly consist.

Finery process. The hearth is being filled with charcoal considerably above its top, & the fire blown up by a pair of pretty large bellows, more charcoal being from time to time supplied as occasion requires; the finer lays upon the fire, of the produce of the last process about 100 pounds with a covering of charcoal over it. The metal, as the operation advances, sinks lower, becomes hot, goes into fusion, and drops through the fire to the bottom of the hearth; where escaping the violence of the heat, it grows cooler, and resumes in some degree its solid state. As soon as all the metal is gone down, it is by the help of an iron crow called by the workmen a fourgon, raised again to the top of the fire, and is melted down again to the bottom of the hearth. If the metal had no bad quality which made it require a longer

1 Termed 'second' process by the author in contrast to the first which was conducted in the blast furnace.
2 Added above the line: ‘3 or 8 inches deep Reaum (ut), which is taken from R. A. F. de Réaumur, L'Art de convertir le fer forgé en acier, p. 244. Paris, 1722.
3 Added: ‘(a pig of 100 or 150 pound, Cocksh(u))’.

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continuance in the fire, and if the operation has been properly conducted, the process is now finished, all but what belongs to the hammer. But that it may be the better understood, I shall describe the effects at the three different stages.

Separation of cinder, metal becomes less fusible. The first fusion separates from the metal a small proportion of a very corrosive scoria, and renders the metal much more difficult to flux again; and it therefore after the first elevation goes down a second time in a less fluid state, when the quantity of scoria, or cinder as they call it, is also considerably increased. And at the third time it is melted down, it drops through the fire scarce so fluid as bricklayers mortar, during which operation a large proportion of cinder is separated from it, which is let off, on a redundance, through the hole in the iron plate mentioned above; and the redundance is constantly known by the snuffing of the blast, occasioned by the interruption it meets with from the cinder at the nose of the tuiron.

Difference of first & later cinder. The change made in the cinder, in the progress of the whole operation, is no less remarkable, and thence the finer forms his judgement of the success of it. That which was at the beginning exceeding corrosive, and fumed and sputtered like liquors in fermentation, at the last becomes mild and flows like wax: and the mass at the bottom of the hearth, instead of the fragile reguline substance, which, so far from being tractable with the hammer, constantly broke to pieces on being elevated from the bottom of the hearth, is become a tolerable connected lump of malleable iron, or rather a spongy mass, whose fibres are composed of malleable iron, having the interstices filled with the cinder above described.

Forging. It is now taken out of the fire, under the name of a Bloom or Loupe; and after the external crust of coals and cinder has been a little broken off by a few strokes of a hammer, and a pair of tongs have been properly fitted to it, the finer drags it along the iron-paved path of the forge to the great hammer, by means of the strokes of which the cinder is squeezed out, and the malleable part formed into an octahedral prism, of about 20 inches long, & four larger & four lesser sides: it then takes the name of a half-bloom. In this state it is carried back to the finery, and has one of its ends plunged to the bottom of the hearth, a fresh quantity of pig metal being laid on the top of the fire, in order to begin a repitition of the process. It will be proper to observe, that what is here described is the making of the first loupe, which is always attended with more difficulty, and takes a longer time, than any of the succeeding processes, which are greatly facilitated by the well digested cinder which has now filled the hearth, and which, as it should seem, like a ferment, has the power of assimilation. As soon as the half-bloom is perfectly hot, it is carried back to the great hammer, and one half of it, all but a small lump at the end, is formed into a bar of iron.

Chafery. It is now called an Ancony, and thrown aside, to be taken at a proper time to the chafery (another hearth every way more capacious than the finery, and particularly adapted to this use) and is by the Hammermen (so the operators at it are called) with the help of the great hammer, formed into bars or what other shape is required.
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