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# The BP Book of Industrial Archaeology

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# The BP Book of Industrial Archaeology

NEIL COSSONS

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David & Charles  
Newton Abbot . London  
North Pomfret (Vt) . Vancouver

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## Preface

To indulge oneself in reminiscences is something which occurs all too infrequently, so this preface affords one of those rare opportunities for which I make no excuses. In looking back on the development of my own interest in industrial archaeology there are several quite specific events which I remember with vivid clarity as well as others which were no doubt equally significant but which by their nature are hazy and diffuse. The germ of the infection was without doubt caught from my father whose interest in turnpike roads led him and later both of us to seek out bridges and tollhouses, and those remaining milestones which had not been buried or destroyed in the war. A journey by Barton's bus (were Barton's buses *really* all different?) from Beeston near Nottingham to Shardlow to see the flood-damaged remains of Cavendish Bridge brought me into contact, for the first time consciously, with a place which breathed the atmosphere of the Industrial Revolution and of past prosperity and activity, the inland port on the Trent and Mersey Canal with its superb warehouses and basins. There was a magic about deserted Shardlow. Here was a *place* where things had happened but where nothing happened now. On the line of the Ashby and Ticknall Tramway or the Charnwood Forest Canal, at King's Mills on the edge of Donington Park, beside the remains of the Morley Park blast furnaces at Heage or the great mills at Cromford, this sensation of place became overwhelming, the essential ingredient which stimulated the imagination and brought alive for me the men and horses, the boats, wagons, flames and smoke of a period which was otherwise as distant and unreal as that of ancient Egypt or Rome. There were also from time to time interminable Sunday afternoons which then passed me by completely, when my father's smoke-filled study was full too of J. D. Chambers or W. E. Tate or on occasion both. They were decrying the desecration of Nottingham in a period before a conservation movement existed—and so the threatened extinction of the Collins almshouses in Friar Lane inexorably became a reality. Who could stand in the way of progress?

Much later, with Michael Rix at Preston Montford in Shropshire, I realised there were lots of other people with broadly the same sort of interest

and that it was gaining a corporate identity under the name 'industrial archaeology'. But by then I was already in the business myself and the opportunities to practise were broadening rapidly. The diversity of the interest in industrial archaeology was, and still is, astonishing and has undoubtedly been one of the great aids to its rapid evolution over the last couple of decades, to the growth of a broad base of popular interest and to the awakening of an active appreciation that the remains of industrialisation in Britain are the tangible marks of the beginnings of a new civilisation which a thousand years hence the archaeologist and historian will identify, categorise and possibly revere in the same way as we do the ancient cultures of the Mediterranean. With the Industrial Revolution period, however, we have the opportunity to keep the surviving remains alive because we are close enough to identify with the people who were involved. This book is largely concerned with the physical remains as such, with sketching in their historical and technological background and with guiding the visitor to the *place* where his imagination may be stimulated.

In compiling this work I owe thanks to many people who have offered encouragement and given me active help and advice. My wife and children have entered very much into the spirit of industrial archaeology; at the age of four my daughter Elisabeth could recognise a tower mill at half a mile, model blast furnaces clutter the bedroom of her elder brother Nigel, while Malcolm, who was born during Chapter 4, is already showing signs of becoming infected too. My colleagues at Ironbridge have made many useful suggestions and brought to my notice innumerable sites of interest. To Brian Bowers, Ivor Brown, Keith Gale, Charles Hadfield, John Iredale, Kenneth Major and George Watkins I am particularly grateful, for their kindness in reading sections of the draft text and giving invaluable comment and criticism. I am deeply indebted to Peter Stoddart, who prepared the line drawings, for his painstaking attention to detail and his sensitivity to the problems of interpreting mechanisms in what we both hope will be a comprehensible manner. Brian Bracegirdle was also of very great assistance with the visual aspects of the book in making available to me photographs from his wide-ranging collection. Angus Buchanan, whose friendship I have enjoyed over many years, has been of great help and encouragement to me and to Kenneth Hudson I have been continually indebted for jerking me out of those inadvertent lapses into antiquarianism into which anybody involved

in archaeology is so easily inveigled. Gordon Payne deserves my special thanks for his numerous and helpful suggestions and his comments on the draft manuscript.

Many other people have supplied me with information, verified facts and offered suggestions and without their help this book could not have been written. In recording their names here I am expressing my gratitude but at the same time in no way wish them to be associated with any errors of fact or of emphasis, for which I am wholly responsible: David Anderson, Frank Atkinson, Kenneth Barton, John Butt, John Cockcroft, Arthur Corney, Joan and Roy Day, Paul Elkin, Keith Falconer, Bill Gilmour, Douglas Hague, Bob Hawkins, Kenneth Hawley, Dan Hogan, John Hume, Derek Janes, Michael Lewis, Jeremy Lowe, Morgan Rees, Michael Rix, John Robinson, John Sawtell, Michael Stammers, John Stengelhofen, Donald Storer, Michael Thomas, Barrie Trinder, Rex Wailes, Margaret Weston and Peter White.

Ironbridge

N. C.

## Preface to the Third Impression

IN a little over the three years since its first appearance, the *BP Book of Industrial Archaeology* is going into its third reprint, just one indication of the increasing popularity of industrial archaeology in Britain and overseas. Much has happened since 1975, including the publication of a new journal, *Industrial Archaeology Review*, produced by Oxford University Press in conjunction with the Association for Industrial Archaeology, and, at a more popular level, of the magazine *Industrial Past*.

The Industrial Monuments Survey, administered since 1959 by the Council for British Archaeology, has now passed wholly into the care of the Department of the Environment, the first step in what it is hoped will be a bigger involvement of the Department in industrial archaeology.

There has been considerable progress in the field of preservation too, including the opening to the public of steam pumping stations at Hereford and Kew Bridge, and at Hove where the Goldstone engines have become the nucleus of the Brighton & Hove Engineium. Several major museum projects are under way of which the North Western Museum of Inland Navigation at Ellesmere Port, the Black Country Museum in Dudley and the Chatterley Whitfield Mining Museum in Staffordshire are perhaps the most significant. Of those that are already open, two, the Gladstone Pottery Museum in Stoke and the Ironbridge Gorge Museum in Telford, have been named the Museum of the Year 1976 and 1977 respectively. In 1978 Ironbridge became the first winner of the new European Museum of the Year Award.

Adaptation of industrial buildings to new uses is also becoming widely recognised as a means of allowing an important or interesting building to earn its keep rather than be destroyed. St Katharine's Dock in London and Bush's warehouse in Bristol both now fulfil new roles, the former as an hotel, conference and residential complex, the latter as a new home for the Arnolfini Gallery. Perhaps these encouraging signs will precipitate a more constructive approach to the finest of our dockland monuments, the great Albert Dock warehouses in Liverpool.

Neil Cossons  
Ironbridge  
February 1978

# 1 A Perspective on the Nature of Industrial Archaeology

IN the history of mankind the Industrial Revolution in Britain was a unique phenomenon whose repercussions have spread throughout the world. We live today in a society whose economy is essentially industrial, our prosperity is based on the fruits of industrial activity and our surroundings, both urban and rural, are largely the result of over two centuries of progressive industrialisation. Industrial archaeology is concerned largely with those surroundings. In simple terms it is the examination and analysis of the physical remains of the Industrial Revolution period.

The traditionally accepted archaeologist is one who investigates past cultures by delving into their surviving remains, and his primary investigative technique is often excavation. The results of excavation as a means of acquiring evidence have enabled archaeologists over the years to establish the chronological and geographical divides in man's evolution and to classify particular periods by specific characteristics, often based on a type of technology. Thus we have periods identified by man's use of stone, bronze or iron implements, by the dominance of an imperialist culture like that of the Romans, or by a more straightforward chronological division of convenience, as with medieval archaeology. It might appear logical that the period of industrialisation should receive similar treatment, but until relatively recently this has not been done. Firstly there was a failure, perhaps because of the closeness in time, to recognise the full implications of the Industrial Revolution in cultural terms, coupled with an all too clear appreciation of the damage and suffering which it had caused. On the other hand historians had been looking at aspects of the industrial period using documentary sources for their evidence for many years; in other words the accepted investigative technique was one based on archival research rather than excavation. The historian, interpreting his evidence to shed light on the nature of a period, was fulfilling the same role as that of the archaeologist whose only source of information might be what he found by digging for it.

However, in the last 20 years or so there has been a growing appreciation

that the physical remains of the Industrial Revolution period might also have some significance as sources of evidence. The growth of a widespread interest in those remains, on the other hand, has been motivated by much more deep-seated and emotionally based feelings than the purely academic recognition that they were a source of potentially valuable information. The interest is more than simply 'archaeological', a fact which has led to much questioning of the validity of the term 'industrial archaeology' and to an almost obsessive desire to define it and justify its existence. It is essential, therefore, in reaching our own definition of the subject not to resort to excessive pontification or the setting of strict and rigid boundaries around something which is so new, so dynamic in character and in such a fluid stage of development. Industrial archaeology will define its own boundaries, techniques and disciplines, given time.

We have suggested that industrial archaeology is, in essence, a period or cultural archaeology as Neolithic archaeology, Roman archaeology or medieval archaeology are. It is the archaeology of an era, which in Britain is reasonably well defined, called the Industrial Revolution. As a term, therefore, industrial archaeology has its greatest relevance when seen in the context of more traditional archaeological period divisions. One of its shortcomings has been the word 'industrial', which has created problems of definition. Some interpretations suggest that industrial archaeology is concerned specifically with buildings and machines directly associated with industrialisation in the last 2½ centuries. Others deny the period division and regard the subject as covering any industrial activity of whatever date from flint axe factories and Roman bread ovens to the Industrial Revolution and even later. If we accept the traditional archaeological approach, however, industrial archaeology might be defined as embracing an epoch in man's evolution, an epoch which in this case has been characterised by industrialisation. Perhaps 'modern archaeology' would be more appropriate.

The Industrial Revolution period provides then the core area, the main-spring of industrial archaeology. But there is a diffuse penumbra too, into which the industrial archaeologist, like the archaeologist of any other period, must go to provide a perspective and context for his main area of interest. Industrial archaeology spreads out chronologically, in terms of subject area and in terms of technique well beyond its obvious centre—hence the need for flexible boundaries. Like any other archaeologist (or historian), the

industrial archaeologist must have an understanding of the antecedents of his particular area of study. Thus the evolution of wind and water power in the eighteenth and nineteenth centuries can only be fully appreciated in the context of much earlier developments. But to regard industrial archaeology as being concerned with only *industrial* activity within the last 2 centuries or so is also to reject the cultural definition. The industrial archaeologist, if he is to have any real understanding of the sites and artefacts of the Industrial Revolution, must look at the landscape in its entirety. Industrial archaeology is in part a landscape study, and the industrial archaeologist cannot restrict himself wholly to the thematic approach. The Industrial Revolution created a new economy, a new landscape, a new way of life. In terms of the lives of all of us, as inhabitants of an industrial nation—the first industrial nation—it is the most relevant period of our past, not only because it is the most recent but because the specific changes wrought during the last 2½ centuries provide the foundations of our present society and of all other industrial societies throughout the world.

This one word 'relevance' provides the key to the phenomenal growth of interest in industrial archaeology in recent years—a widespread realisation that this particular period of our past was in world terms unique and that amongst its physical remains are monuments of outstanding and exceptional significance. There had been no Industrial Revolution before in the world, and no other nation's subsequent progress towards industrialisation had the same spontaneity, generated the same range of technological innovations or produced the same landscape changes. Industrial archaeology was thus born not out of a detached or academic interest but on a wave of emotional involvement and a deep-seated feeling that a vital part of our past was being destroyed. The ambient conditions of the mid-1950s were exactly right for the growth of this new interest. The postwar years were dominated by a preoccupation with growth in an obsessive, almost nineteenth-century, way—with the creation of new industry, new towns, a new foundation for future prosperity—but at the same time coupled quite specifically with the destruction of much which was old. For once the occurrences of the past provided the lessons for the future and the new period of exploitation of resources created a backlash—a vital and dynamic feeling for the environment based on an appreciation, for the first time, that it was delicate and sensitive to uninformed meddling. The Industrial Revolution had provided the awful

example, and while most people recognised that the worst excesses of industrialisation had to go, they recognised too that society was not in a sufficient state of moral responsibility to prevent the same sort of thing from happening again. The growth of industrial archaeology is just one facet of this widespread interest in the landscape and its future.

Other factors contributed to the growth of industrial archaeology. Not only did the destruction of huge areas of eighteenth- and nineteenth-century Britain create a reaction and an awareness of their significance but the preoccupation with the stimulation of new economic activity resulted in past periods of growth and their achievements taking on a new fascination. The physical monuments of those who had so spectacularly generated growth in the Industrial Revolution were appreciated in a way which would have been impossible in the 1930s, when industry was associated in the minds of everybody with unemployment, decay, desperately miserable towns, and landscapes of destruction. The mid-1950s, therefore, saw for the first time the growth of a national pride in past industrial achievement which began to counterbalance those adverse social consequences that had formerly been so wholeheartedly associated with it. There was thus the curious phenomenon of a new and widespread environmental awareness arising in response to the depredations of postwar development and the fear that 'history might repeat itself' coupled with the beginnings of an appreciation that the Industrial Revolution period, so long held in disregard, was of very special significance and that some of its physical remains formed, in effect, the real and tangible evidence of the origins of our present culture. This paradox has caused the industrial archaeologist some difficulty in establishing his credibility, particularly when it comes to the preservation of sites and areas which are historically significant but are outside the currently accepted and relatively narrow areas of contemporary aesthetic appreciation. Nevertheless, within this new climate of environmental and historical awareness, industrial archaeology was able to grow from a seed into a sturdy sapling.

The factors providing the essential motivation for the widespread interest in industrial archaeology were therefore numerous, embracing not only the recording of the archaeological evidence which sites might hold but the desire to preserve a vital part of the national heritage. In addition came new interest, in the aesthetic aspects of industrial artefacts, a further stimulation to the enthusiasm for things mechanical which had always had a large

following, and more recently the appreciation of some of the possible social benefits which the conservation of, for example, industrial residential areas might have. Industrial archaeology has thus grown to be a broad-based study encompassing more than the words 'industrial' and 'archaeology' would seem to imply. It is already inconceivable that another, more appropriate, term will ever emerge to supplant it. 'Industrial Archaeology' is obscure in origin but was probably coined in Manchester in the early 1950s. Its first appearance in print occurred in 1955, when Michael Rix published an article in *The Amateur Historian* emphasising the need to record and preserve the remains of industrialisation before they disappeared.

The dynamism which has characterised the growth of industrial archaeology over the past few years has resulted from the fact that large numbers of people with differing backgrounds of work and education can make a real contribution to its advancement. As a study it draws its life-blood from a wide variety of disciplines, demanding an appreciation on the one hand of economic or social history or geography and on the other of a knowledge of mechanical or civil engineering, of metallurgy or architecture. But because it is so all-embracing, almost anybody, regardless of any specialist knowledge or skill, can make a contribution in one way or another. Industrial archaeology, like the other archaeologies, has attracted a wide variety of people from many different walks of life, and numerous local societies have been formed. Unlike traditional archaeology, however, industrial archaeology has not developed a caucus of trained professionals—there is as yet no way of becoming a qualified industrial archaeologist.

This broad base of awareness which enabled industrial archaeology to gain ground so rapidly has been both its strength and its weakness. Lacking respectable academic origins, industrial archaeology has been the subject of considerable criticism, its inter-disciplinary nature and absence of accepted technical standards making it unpalatable to many traditionally based academics. Nevertheless the problems of industrial archaeology have caught the imagination of large numbers of people, who as amateurs or professionals are rapidly gaining the skills necessary to achieve the right sort of standards. Industrial archaeology has developed, generally speaking, outside the orbit of traditional archaeological activity, and only very recently have industrial archaeologists begun to pick up the well established techniques of the traditional archaeologist and apply them to this new study. There are few

practical techniques peculiar to industrial archaeology, although some, such as the recording of machinery and various aspects of conservation, pose specific problems which will undoubtedly provide the foundation for considerable industrial archaeological research in the future.

It is becoming increasingly clear that the industrial archaeologist by working in the field, analysing sites, can make a real contribution to our sum total of knowledge. In other words there is a truly 'archaeological' element of the study, the potential of which has hardly been developed. Not only is the industrial archaeologist, in his role as a fieldworker and interpreter of the landscape, in a position to provide an extra dimension to the existing findings of historians who have used only documentary sources but there are a number of areas of investigation where field evidence is itself the primary source. For example, no documentary information exists to provide a detailed explanation of the development of iron railways, or plateways, from the mid-eighteenth century onwards. Archaeological evidence alone exists to reveal the regional differences between various types of primitive plateway, the technology of their track systems, rail and sleeper design and earthworks. Documentary evidence fails to provide information on the philosophy applied to their capitalisation but the industrial archaeologist in the field, using the simplest techniques of observation and surveying, can readily appreciate the fact that some early railways were literally laid on the existing ground surface while others, designed to fulfil the same function, needed massive earthworks with major embankments, cuttings and bridges.

Similarly, industrial archaeological investigation has provided conclusive evidence of the evolutionary stages in the transition from timber to iron framing in factory buildings. Again, no extraordinary techniques have been used, merely those already developed by historians of architecture; but without the availability of the physical remains of the buildings themselves our understanding of this fundamental advance in structural engineering would be incomplete. Metallurgical analysis applied to the slags of early blast furnaces provides yet another example of physical remains yielding evidence of value. Although by no means restricted to Industrial Revolution sites, slag analysis enables the historian of metallurgy to gain a good idea of the raw materials used and their sources, the temperatures at which the furnace operated and the nature of the finished product. As yet in its infancy, laboratory analysis of slags, and indeed of the metal products themselves,

may provide a relative dating technique of great importance.

A completely different approach to site evidence is the area surveying and mapping of types of industrial installation, workers' housing, watermills or mine shafts as a means of establishing distributional patterns. Here the techniques of the geographer and statistician are required, coupled, as always, with an understanding of the general picture of economic activity. Relations can be established between types of waterwheel and the gradient profile and consistency of flow of streams, between blast furnace design and the qualities of the raw materials charge, between topography and the flue arrangements of lead smelters and between surface geology and road turnpiking. These are all simple examples of the role field evidence can play in the assembly of information. The industrial archaeologist then is a correlator of evidence, synthesising data from documents, maps and field remains to gain a general picture.

The artefacts of industrialisation can in other ways also provide an appreciation of the evolution of technology which would be quite impossible from documentary sources. Many of the innovations which formed the basis for progress in the eighteenth and early nineteenth centuries were brought about by craftsmen whose contribution was rarely, if ever, documented. Frequently the situation arises of a company with substantially complete commercial records being able to give no information at all on the manufacturing processes which provided the foundation of its existence. The key to the understanding of these processes is in the surviving artefacts, which may take the form of the manufacturing equipment or the products that were made with it. They often also provide an insight into the lives and intellects of the people who made and worked with them far more potent than any written evidence could do, even supposing it existed. The craftsman as an innovator as well as a producer, personally and physically involved in the manufacturing process, using the craft skills he had acquired through an apprenticeship and which he applied intuitively in his everyday work, was fundamental to the progress of industrial technology. James Nasmyth, himself an inventor of some stature, wrote of that great craftsman, entrepreneur and innovator Henry Maudslay, with whom he worked for a time as an assistant: 'To be permitted to stand by and watch the systematic way in which Mr. Maudslay would first mark or line out his work, and the masterly manner in which he would deal with his materials and cause them

to assume the desired forms, was a treat beyond all expression. Every stroke of the hammer, chisel or file, told as an effective step towards the intended result. It was a never-to-be-forgotten lesson in workmanship in the most exalted sense of the term.' Herein lies what much of industrial archaeology is all about: appreciation and understanding of the genius for innovation and the skill in making things combined with recognition of the practical and aesthetic qualities of workmanship, for which the original object is essential.

The physical remains of industrialisation thus far transcend in importance their role as pure historical evidence, which fact has provided the primary motivating spirit behind the widespread interest in industrial archaeology. To an increasing number of people the engines and machines, factories, mills and warehouses, canals and railways which came to dominate the landscape in the last 2 centuries have become significant as part of our cultural heritage; they are implanted in the subconscious of innumerable ordinary people who, with no background of scholarship or training in artistic or architectural appreciation, find themselves responding aesthetically to the sweep of a railway curving through a wooded valley, to the triumphant striding of a viaduct, to the sound and smells of a perfectly running mill engine or the rhythm and symmetry of an eighteenth-century textile mill. Not only do these monuments to industrialisation represent a functional perfection of design but their heroic scale, often so perfectly assimilated into the landscape, excites the imagination and stimulates the senses. They represent the skill and inventiveness, adventurousness and suffering of the first Industrial Revolution. Their study and preservation is the justification for industrial archaeology.

#### THE GROWTH OF INDUSTRIAL ARCHAEOLOGY

As we have seen, industrial archaeology is relatively new, but some people had been concerned with it very early on. As early as the Great Exhibition of 1851 it was appreciated that there were technologically important machines dating from the early years of the Industrial Revolution that were worthy of presentation to the public. The beginnings of what is now called the Science Museum, in London, were a tangible expression of this appreciation, and items such as early stationary steam engines and railway locomotives

were collected and preserved. Indeed the importance of preserving locomotives was recognised at a remarkably early date, with the result that Britain, the birthplace of the steam railway, possesses a very complete series of early examples, including, in the Science Museum alone, *Puffing Billy* of 1813, and *Rocket*, *Sans Pareil* and *Novelty* of 1829, all three of which were competitors at the Rainhill trials. Museums in Edinburgh, Newcastle and York also contain pre-1830 locomotives. The York Railway Museum, opened in 1928 by the London & North Eastern Railway in the aftermath of the Stockton & Darlington Railway centenary celebrations of 1925, was the first large museum of its type, and another exhibition, in Newcastle-upon-Tyne, provided the initial collections and led to the opening there of the Museum of Science & Engineering in 1934. These are all museums of the traditional type in which exhibits are collected and brought into a building where they are, space permitting, exhibited to the public, and the justification for most of these early collections was that the items in them represented outstanding contributions to the development of engineering and technology; in many cases they were 'firsts'. Little if any recognition was given to the social or economic context of the material collected.

Active study of at least the technological aspects of industrialisation is also much older than industrial archaeology and centres largely around the work of the Newcomen Society, which was formed as a result of the James Watt centenary celebrations held in Birmingham in 1919. Its object is to support and encourage study and research in the history of engineering and technology, and the preservation of records, both technical and biographical. Although the society takes its name from Thomas Newcomen (1663-1729), the father of the steam engine, its interests cover all aspects of industrial, and in some cases pre-industrial, technology. The *Transactions* form an invaluable source of information, and to these and the dedication and enthusiasm of Newcomen members over more than 50 years, industrial archaeology owes a great debt. There were, of course, individuals working in the field and publishing the results of their work in the transactions of local archaeological, historical and philosophical societies. An early and unusual example deserves note because of its title, 'The Archaeology of the West Cumberland Coal Trade' by Isaac Fletcher, published in the *Transactions of the Cumberland and Westmorland Antiquarian and Archaeological Society* in 1878, but there is no evidence that this use of the term 'archaeology' in the context of industrial

remains had any influence on the development of the modern term 80 years later.

The spontaneous growth of industrial archaeology in the late 1950s and early 1960s manifested itself in a variety of ways. Workers' Educational Association and University Extra-Mural Department classes were some of the first 'formal' gatherings of people interested in the subject, together with a number of regional conferences from which grew the first local industrial archaeological societies. Almost invariably the driving force behind these newly formed groups was the need to record industrial monuments before they were destroyed, and the early lead given by the Council for British Archaeology (CBA) in establishing a basic recording system provided a focal point and stimulus of considerable importance.

In 1959 the CBA established an Industrial Archaeological Research Committee as a means of extending into this new field its existing role, which it had played since its inception in 1945, of coordinating the work of regional archaeological societies. Subsequently an Advisory Panel was set up as a sub-committee of the Research Committee in order to develop policies for the recording of industrial monuments and, in the event more important, procedures for ensuring that they received the right sort of legislative protection. The then Ministry of Public Buildings & Works, the government department responsible for scheduling ancient monuments, also recognised at least the theoretical need for an active policy towards the recording and preservation of industrial sites and, in conjunction with the CBA, launched the Industrial Monuments Survey (IMS). Rex Wailes, a pillar of the Newcomen Society and an authority on windmills, was appointed full-time consultant to the Survey, and he undoubtedly played an important role in his travels throughout the country in stimulating industrial archaeological work at a local level. Later the Survey was transferred to the care of the CBA, to whom the Ministry, now part of the Department of the Environment, makes a cost-covering contribution. On the retirement of Mr Wailes, Keith Falconer was appointed Survey Officer, reporting to the Advisory Panel and the Research Committee. His work, carried out on a region-by-region basis and in consultation with innumerable local fieldworkers, enables the CBA to recommend industrial monuments for Scheduling, under the Ancient Monuments Acts, and Listing, under planning legislation, thus bringing industrial archaeological sites into line in law with those of

other periods.

As part of its policy to embrace industrial archaeology, the CBA also initiated a record card system with the object of establishing a 'national record' of industrial monuments and provide the Survey with a basis for defining its priorities for listing and scheduling. This system was based on a record card designed to be filled in by fieldworkers and, despite its well recognised inadequacies, this National Record of Industrial Monuments (NRIM) has provided the only theoretically comprehensive and all-embracing record of industrial sites for over 10 years. In its early years the NRIM suffered from lack of a tight definition of how the cards should be used and, with their compilers ranging from groups of schoolchildren to trained engineers, architects and museum curators, the results have inevitably been uneven. Not only is there a wide variation in the quality of the entries but their spread nationally reflects the distribution of active fieldworkers rather than of industrial sites. Very few local societies have systematically used the CBA card as the basic recording instrument to work over an area, although individuals with specialist interests have made attempts to cover specific subjects comprehensively. Despite these failings and the fact that the NRIM has not provided its originally intended service to the Industrial Monuments Survey, it is the only existing record with anything like a national coverage, and although it does not generally offer much information on specific sites, it could form the basis for a national inventory.

An important contribution to the administration of the NRIM came in 1965, when it had become increasingly clear that the CBA and its Survey Officer could not offer the secretarial facilities necessary to operate the system properly. As a result the Director of the Centre for the Study of the History of Technology at the University of Bath, Dr R. A. Buchanan, offered to provide a base for the Record, and it has been operated from there ever since. Cards are filled in and returned to the Centre for copying. The original is returned to the fieldworker concerned and the three copies made are filed for reference, one with the CBA, one with the National Monuments Record and one at the University of Bath.

Industrial archaeology, however, has now outgrown the sort of record represented by the NRIM, and important decisions about its future must be made before long. Most important perhaps is the need to make clear to local societies and individual fieldworkers what the needs are, particularly in

relation to sites which are threatened with destruction. Here the continued existence of the NRI, unless supported by other mechanisms for more sophisticated recording, could form a positive drawback to industrial archaeology, as many people, having filled in a card, feel that they have fulfilled the necessary archaeological obligation towards a site about to be destroyed.

The situation today then comprises a basic national record in the form of the NRI, the CBA Survey Officer in close touch with appropriate inspectors and investigators in the Department of the Environment, and a wide variety of regional recording systems ranging from the superb work of the Royal Commission on Ancient and Historical Monuments of Scotland (unfortunately not paralleled in England and Wales), to building surveys by schools of architecture, photographic and drawing surveys by some local authorities and, very selectively, by the National Monuments Record, and various record data assembled by some museums. The assembled information compiled over the years by the CBA Survey Officer provides a surprisingly comprehensive basic record of sites, while there are certain specialist records such as that of wind and watermill sites put together by the Wind and Watermill Section of the Society for the Protection of Ancient Buildings. As if this is not enough to bewilder the newcomer anxious to make his contribution to industrial archaeology, he is also faced with an increasing number of local or regional gazetteers of sites covering, for example, Devon, the Bristol area, Bath, Greater London, Hertfordshire, Bedfordshire, Sussex, Wiltshire and Lancaster.

How then can the uninitiated amateur make contact with what is going on in his region? Firstly, there are the numerous local societies (listed in Appendix 3) which cover much of the country. If there is no local society, contact with the Council for British Archaeology may result in a link being established with one of the fourteen regional CBA groups, some of which have industrial archaeology sections. If nothing comes of this approach, try the local museum, which may afford one an opportunity to be involved in survey work and/or a practical contribution to preservation. Lastly, but perhaps most important, there are WEA and university extra-mural courses, which teach the techniques and at the same time allow one to participate in what work is going on. Although only the two universities of Newcastle-upon-Tyne and Hull have staff tutors concerned specifically with industrial

archaeology, almost all run courses of some sort, usually with outside lecturers.

One of the curious aspects of the development of industrial archaeology over the last 20 years has been the absence of any central society or co-ordinating body concerned specifically with its needs. The nearest approach has been the CBA's Industrial Archaeological Research Committee. In other branches of archaeological activity the situation is quite different; there are a number of national organisations representing all aspects and periods of traditional archaeology, together with specific societies covering, for example, prehistoric, medieval and nautical archaeology. In addition there are organisations such as the Victorian Society or the Georgian Group, concerned primarily with architecture but impinging on industrial structures to some extent. The Newcomen Society, though already well established and respected in the field of engineering history, does not fill the apparent gap, as its concern is by no means primarily 'archaeological'.

This central 'vacuum' within industrial archaeology was partially filled until quite recently by two things. One was the journal *Industrial Archaeology*, inaugurated in 1964 and still the only national periodical for the subject in Britain or, for that matter, anywhere in the world. Initially edited by Kenneth Hudson, whose book of the same title published in the previous year was the first general text on the subject, it is now published in Scotland under the editorship of Dr John Butt of the University of Strathclyde. The other focal point for industrial archaeology in Britain was the annual conference held initially in the University of Bath, which from 1966 onwards provided a yearly opportunity for industrial archaeologists to assemble, exchange views and discuss mutual problems. Before long it uprooted itself and moved to Bradford, Glasgow and, in 1973, the Isle of Man. By now the need for a national organisation was becoming imperative, and it was this annual conference which provided the obvious opportunity for its conception. Inaugurated in March 1974, the new Association for Industrial Archaeology has been set up to represent the interests of industrial archaeology at a national level, to assist and coordinate the work of existing regional groups and to continue the well established pattern of annual conferences. A *Bulletin* is produced six times a year. The AIA has not been formed to compete with or replace the CBA, or to challenge its relation with government departments, but to strengthen its hand, press for more support for industrial

recording and conservation and improve the 'watchdog' surveillance so necessary to prevent important structures being demolished willy-nilly.

#### CONSERVATION

The dynamic growth of industrial archaeology throughout the 1960s was instigated by an awareness that Britain's industrial heritage was vanishing and the new 'movement', if such an all-embracing term is appropriate, manifested itself in two quite separate bodies of activity—those who recorded and those who conserved. Naturally enough there was some overlap between the two but distinct areas can nevertheless be identified, with local industrial archaeological societies engaged primarily in recording, an increasing number of established museums expanding to embrace industrial archaeology and, perhaps most important, a wave of trusts being set up to preserve industrial monuments *in situ*.

We have already touched on the involvement of museums, both nationally and locally financed, in industrial preservation well before industrial archaeology was born. The Science Museum in London needs no introduction as the national museum of science and technology, while the three other national museums, in Cardiff, Edinburgh and Belfast, all have well established departments of industry or technology with trained curatorial and technical staff. From the point of view of conserving industrial artefacts, however, all have reached that situation in which the museum as a building, as opposed to the museum as an institutional organisation, is now markedly unsuited for what it has always traditionally been supposed to do. The reaction has been curious and not altogether satisfactory. Some museums have bent over backwards to continue their traditional role, so that one has the remarkable sight in Edinburgh of an immense industrial waterwheel incorporated, without the machinery it drove, in a new museum building, while in the National Maritime Museum at Greenwich the dismembered remains of a paddle-tug have been similarly treated. Conservation is a function of all museums, and their basic philosophy must therefore stem from the most satisfactory means of achieving this end. All these national museums have large items of industrial material in store, which at least means that they have saved equipment from destruction; it is important now to ensure that the museums themselves do not destroy primary exhibits

in order to 'make them fit'. Clearly there are opportunities, where several items of the same type survive, to dismantle or section in order to explain and interpret their method of operation (indeed not enough of this sort of thing is done with, for example, locomotives), but, as with all other types of museum collection, the integrity of the primary material must be maintained intact. The National Museum of Wales has realised its conservation responsibilities admirably with the retention *in situ* of the Dinorwic slate quarry workshops, and with its plans to develop site museums for coal-mining in Glamorgan.

Provincial museums have also responded to the demands of industrial conservation by setting up departments to collect machinery, although few have yet had the opportunity to present it to their public. Several have been able to acquire a suitable site, with its own intrinsic importance, and develop that as a museum. Thus Leicester Corporation has taken over the disused Abbey Lane sewage pumping station in the city to preserve the four beam engines and develop the site as a museum of technology for the East Midlands. Generally speaking, however, the established local authority museum has not responded, either through lack of money or lack of interest, to the conservation demands posed by obsolete industrial buildings and the machinery they contain. The net result has been the formation of numerous private bodies, most of which are registered with the Charity Commissioners as trusts, in order to conserve, usually on site, important industrial monuments. It would be wrong to imagine that all these have developed as a result of the recent growth of interest in industrial archaeology, although by far the majority have done so. Several wind and watermill preservation schemes have been going for many years: the Cornish Engines Preservation Society, formed as early as 1935 and now incorporated into the Trevithick Society, preserved several Cornish mine engines before handing them over to the National Trust, while in Sheffield the Council for the Conservation of Sheffield Antiquities was instrumental in restoring the cutlers' grinding shop known as Shepherd Wheel.

The boom in industrial archaeological conservation, however, is much more recent, reflecting the general growth of the study but more particularly perhaps the higher degree of general concern about demolition of historically important structures and areas of towns. For the first time conservation has had to become a positive and dynamic force in its own right in order to

counter the effects of widespread area redevelopment. In the past an urban area tended to regenerate on a piecemeal basis, a building going here and there and being replaced by another with the same plan and building line. Massive redevelopment, stimulated by the blitz but more particularly the motor car, resulted, virtually for the first time, in huge urban areas being replaced by a totally new landscape bearing no relation whatsoever to what was there before. Few people would argue for the retention of most of what has gone but the great pressures which built up, particularly as the result of road building, have affected much more of our surroundings than just the parts that needed replacement. A sudden state of appalled realisation of the irreplaceable monuments which have been lost, often unwittingly, has generated a widespread reaction, and large numbers of people have become personally involved in conservation projects. The change in the climate of awareness and susceptibility has been quite remarkable, with terms such as 'conservation', 'environment' and 'pollution' receiving such unprecedented exposure that they have become almost hackneyed. In an era during which the word 'Victorian' changed from being a derogatory term of abuse to a mark of approval, industrial archaeological conservation became well established.

Undoubtedly the greatest stimulus to this movement was the destruction of the Euston arch, Philip Hardwick's triumphal entrance to the London & Birmingham Railway. Looking back now on its demolition and the controversy which surrounded it, the Euston arch clearly marked the turning point; it was the initial sacrificial offering necessary to save succeeding generations of structures threatened by redevelopment proposals. What is also particularly pertinent about the Euston disaster is the subsequent realisation that the arch would have had even more relevance, significance and monumentality had it been allowed to perform its original function for the new station. There have been numerous other losses too, including the demolition of the world's first shot tower, in Bristol, for road widening and that of a slightly later but quite different type in Newcastle-upon-Tyne. In Glasgow the magnificent Randolph & Elder engineering building has gone, as has the spectacular group of six Cornish beam engines at Sudbrook, Gloucestershire, which drained the Severn Tunnel. Other losses, as the result of fire, have pinpointed the need for vigilance, where empty buildings are concerned in the case of the great Telford warehouses burned down at

Ellesmere Port, Cheshire, and over structures which are still in regular everyday use as demonstrated by the loss of the Britannia tubular bridge across the Menai Straits.

The requirements of industrial archaeological conservation are multifarious, ranging from the site taken over for its historic significance and preserved as a monument or museum to the need to ensure that important industrial structures which are still in use, such as bridges and tunnels, are not treated unsympathetically by their owners. In addition there is a growing appreciation of the possibilities which obsolete industrial buildings offer for adaptation to new uses. Thus maltings have become concert halls or colour-processing laboratories, warehouses have been converted into flats, granaries into offices and mills into hotels. In Liverpool the city council is considering plans for siting the local polytechnic institute in the empty and long-threatened warehouses of Albert Dock, Jesse Hartley's monumental quadrangle of iron, brick and granite dating from the mid-1840s. This latter type of industrial archaeological conservation is in many ways the most encouraging, as it demonstrates the enormous potential which existing structures have for adaptation and affords excellent opportunities not only to keep buildings and dying areas alive but also to retain the essential architectural, technological or landscape value. The industrial archaeologist has a real and constructive role to play here in the identification of significant buildings and in ensuring that the specific features which make them important are not compromised.

Far and away the most active sector of industrial archaeological conservation activity is represented by private trusts or museum societies of enthusiastic part-time industrial archaeologists whose initiative, ingenuity and prodigious energies have resulted in large numbers of new projects being undertaken in recent years. Many have the support of local authorities and an increasing number receive grants from the Department of the Environment and, if they are in Development Areas, from the national tourist boards. Most are concerned with a specific site, such as a watermill or a pumping station, but others cover substantial areas within which individual monuments are maintained. There are an increasing number of open-air museums which include industrial archaeological material within the scope of their collecting. These are the successors of the continental open-air folk museums in which an area of land is designated and buildings and machines are reconstructed

on it.

About eighty bodies now administer individual sites, and the number is increasing almost weekly. A few examples will give some idea of the general pattern. At Cheddleton in Staffordshire a trust has restored to working condition a water-powered flint mill used originally in the preparation of flint for the pottery industry. Beam pumping engines have attracted particular attention, and private groups have restored to steaming condition the Ryhope water-pumping station in Sunderland, and the Crofton engines on the Kennet & Avon Canal, Wiltshire, which were used to lift water into the summit level. Preserved manufacturing sites are less common, but at Ruddington in Nottinghamshire a local society intends to buy and restore a complex consisting of two framework knitters' shops, together with the hosier's cottage and store. Metalworking projects include Finch Foundry, an early nineteenth-century scythe works at Sticklepath near Okehampton in Devon, and Top Forge, Wortley, in Yorkshire, where wrought-iron railway axles were made. One of the largest organisations with nationwide involvement in industrial archaeological conservation is the National Trust which, besides administering the Cornish engines already mentioned, is responsible for Conway suspension bridge, Nether Alderley corn mill in Cheshire and several watermills in the Eastern Counties, and windmills such as Pitstone Green in Buckinghamshire and High Ham in Somerset.

Local authority involvement in conservation is very varied, illustrating clearly the way in which industrial archaeology 'falls between the stools' of responsibility. In a recent survey on the role of local authorities in industrial archaeological conservation carried out for the Royal Town Planning Institute, the replies to questionnaires revealed that responsibility for industrial monuments rested with departments as diverse as town clerks, libraries, education, records office, archives, engineers and landscape architects. Of the 126 respondents, seventeen said their museums were responsible, while the greatest majority, forty, said that responsibility rested primarily or solely with the planning department or with a joint architects' and planning department. Even within planning departments a variety of sections held responsibility; historic buildings was most common, but urban renewal, conservation and environment were also named. It is clear that industrial archaeology, where it comes into contact with the established order of things, be this represented by an archaeological body, a university, a govern-

ment department or a local authority, has not been able to find a logical and obvious niche in which it can happily be accommodated.

In Sheffield the museum has taken responsibility for Abbeydale industrial hamlet, with its crucible steelworks and water-powered hammers, and the same applies in Portsmouth with Eastney pumping station, in Birmingham with Sarehole Mill and in Shrewsbury with Coleham pumping station. In Derbyshire, however, the planning department has taken the initiative over the preservation of Middleton Top winding engine and sections of the Cromford & High Peak Railway, and there are innumerable other examples up and down the country. It is important to appreciate, however, that conservation of the industrial archaeological assets of a site is not always, or indeed usually, the primary motivation behind a planning department's involvement; the main reason is usually derelict land reclamation, with the provision of scenic walkways, picnic sites and nature trails. It is essential, therefore, for the industrial archaeological viewpoint to be built into the decision-making processes when environmental conservation schemes of this type are mooted to ensure that the archaeological integrity of sites is not destroyed. A similar problem arises, although not quite so acutely, with the application of tourist board capital to conservation projects, as here again it is not primarily the archaeological significance of a site which gains it the grant but its potential as a tourist attraction. The problem, then, is to ensure that the fundamental industrial archaeological conservation principles and priorities are soundly worked out before sites come under the various competing pressures of demolition and redevelopment.

Another area of growth recently has been in the establishment of open-air museums of various types. At Beamish in County Durham a consortium of local authorities supports the North of England Open Air Museum, set up formally in 1970 to establish 'an open air museum for the purpose of studying, collecting, preserving and exhibiting buildings, machinery, objects and information illustrating the development of industry and way of life in the north of England.' Work is now actively in hand on developing the 200 acre site, and the first stage of an electric tramway system to transport visitors around the museum came into operation in the Spring of 1973.

A rather different type of project is the Ironbridge Gorge Museum in Shropshire, set up under the auspices of a Trust formed in 1968. Here the object is to establish a 'network museum' in which the buildings, furnaces,

forges and machinery of this centre of the early Industrial Revolution will be preserved *in situ*. Centred on the Iron Bridge is an area containing many other remains of early ironworking, together with coalmining, brick and tile making and porcelain manufacture. The Coalbrookdale furnace where Abraham Darby perfected his coke-smelting technique in 1709 was originally cleared, and a small museum established nearby, in 1959 by the then owners, Allied Ironfounders, and both are now administered by the Iron-bridge Gorge Museum Trust. Three miles away at the other end of the Gorge is the Blists Hill Open Air Museum, also run by the Trust, which is being developed as a site on to which buildings and machines can be moved when they cannot be preserved *in situ*. Here are colliery winding engines, a re-excavated section of canal, blast furnace blowing engines, a printing shop, a pottery, brick and tile works and numerous other exhibits. Ultimately the area will become a landscape of the past designed to re-create in operational form various industries which contributed to making East Shropshire so important in the eighteenth and nineteenth centuries. Most of the capital for this project, which is estimated to cost something over £1 million, has been raised by appeal to industry, but the Department of the Environment has also made a substantial contribution, notably to the restoration of the bridge itself.

The role of the Department of the Environment is fundamental in the development of industrial archaeological conservation policy and practice. Not only is the Department responsible for the listing and scheduling of industrial monuments but it also makes available capital grants towards conservation work and occasionally maintains sites itself. Numerous projects, both local authority and private, have received grants from the Ancient Monuments Directorate, while money for buildings usually comes through the Historic Buildings Council. It is unlikely that large numbers of industrial monuments will come wholly under the guardianship of the state, as many traditional archaeological sites do; and perhaps only relatively small-scale industrial conservation projects need to. Government assistance to private projects, however, is generally money well spent and a highly effective method of conservation. It is to the largely unrecognised credit of the Department of the Environment that it has made special provisions for industrial archaeology; as early as 1965 the Report of the Ancient Monuments Board recognised that the time had come for a set policy for dealing

with industrial monuments and that this should as far as possible be assimilated, within the framework of existing legislation, into the policy for more traditional monuments.

The legislative protection for industrial monuments, like government sources of money, is diverse in nature, again reflecting the inter-disciplinary nature of industrial archaeology and the difficulty of fitting it neatly into existing compartments. The most important protection is scheduling under the Ancient Monuments Acts, which is designed to register the fact that the preservation of a monument is in the national interest, thereby enlisting the support of owners and others in the protection of the monument and minimising the danger of interference with its essential features. There are now well over 100 scheduled industrial monuments in Britain. Listing is carried out under the Planning Acts and is designed to identify and protect buildings of architectural and historical importance either individually or in groups, as well as buildings which make an important contribution to a townscape. Statutory lists grade buildings into three categories: Grade I covers those of 'outstanding importance', totalling some 4 per cent of the total or about 4,500 in England and 150 in Wales; Grade II covers buildings of 'special interest', with particularly important examples being classified as Grade II\*, the so-called 'Grade II star'; and Grade III covers buildings that do not normally qualify for the statutory lists but are important enough to be drawn to the attention of local authorities and others so that the case for preserving them may be fully considered. Another important piece of legislation of increasing importance to industrial monuments is the Civic Amenities Act 1967, under which conservation areas are designated. Of the 3,000 conservation areas in Britain, about one-third are estimated to contain industrial buildings and in some, such as the Ironbridge and Coalbrookdale Conservation Area in Shropshire, the industrial archaeological features provide the *raison d'être* for designation.

In its short life to date industrial archaeology has evolved at a startling pace, providing a focal point for the interests of many people and affording a new outlook on a vital period of our past. The haphazard nature of some of its techniques is perhaps almost inevitable, but the opportunities exist and are rapidly being grasped for improving the situation and systematising without stultifying the further pursuit of information and evidence. Already industrial archaeology can command large television audiences, is making a

contribution to the growth of tourism and has a rapidly growing range of literature, all developments which would have been inconceivable 20 years ago. Its growth is likely to continue, with a better organised approach to recording, particularly in the field of what might be called 'rescue industrial archaeology', the systematic recording of structures before they are demolished. In the conservation field there may well be a more positive involvement of the Department of the Environment in the running and financing of private trusts, and a recognition, hopefully, by the Department of Education and Science that the conservation and interpretation of industrial monuments, even where it is outside the scope of the traditional local authority museum structure, is a vital part of the national picture. The concept of industrial archaeology as a fully fledged academic discipline in its own right is a long way from realisation, but it may well eventually come. There are already the beginnings of an appreciation that the physical remains of the Industrial Revolution contain a body of information whose isolation and interpretation require a formalised and disciplined approach. Certainly the role of the amateur, or rather part-time, industrial archaeologist—distinctions between amateur and professional are to a great extent irrelevant—will expand greatly, although again based on the evolution of accepted standards of technique, such as those traditional archaeology has established for itself over the last half-century or more. Industrial archaeology is in a way at a turning point, having come through the early stages of youth to adolescence and the verge of manhood. In its progress towards maturity industrial archaeology will be seen in a new perspective, and the viewpoint of the industrial archaeologist will become appreciated as an essential element in the understanding of the society, the economy, the technology and the landscape of the Industrial Revolution. The aim of this book is to point out the remains of the Industrial Revolution that survive and to sketch in something of their context.

## 2 The Industrialisation of Britain

THE industrial archaeologist, as we have seen, is primarily concerned with the examination and analysis of the physical remains of the age of industrialisation, accepting, as would the archaeologist of any other major epoch, that there are specialist antecedents, within various branches of technology, for example, which must be understood before a full appreciation of the events of the period itself can be gained. Before considering the areas of specific interest to the industrial archaeologist industry by industry, it is important to consider the historical, social, economic and technological framework within which something as complex as an industrial revolution could occur. The term 'Industrial Revolution' itself has been in common usage now for nearly a century and was coined at least as early as the 1830s. What was the Industrial Revolution? Why did it happen in Britain first?

Historians have been arguing for three generations over the causes behind the Industrial Revolution, but the accumulated literature is largely the literature of disagreement. What is certain is that at some point, probably in the second half of the eighteenth century—although some would put it slightly earlier—Britain reached the point of 'take-off' into self-sustained growth based on radical changes in methods of production. These changes, occurring over a relatively short time, had widespread repercussions throughout society, the national economy and the landscape. The changes were rapid and their results were there for everyone to see. The rate of change was indeed 'revolutionary'.

The beginning of the Industrial Revolution, therefore, is marked by the start of a rapid rate of change in the economy from one of a backward or underdeveloped country to one of a modern industrial nation. In quantitative terms it might be possible to pinpoint the start of the Industrial Revolution by identifying the date when the gross national product, representing the national income or the total value of goods and services produced in the economy, first began to increase by about 2 per cent per annum, for any pre-industrial economy would be growing at less than 1 per cent per annum. This take-off point occurred in Britain somewhere between 1740 and 1780.

One of the problems of using the term 'revolution', and it was taken from what started in France in 1789, is that it implies instant upheaval, an overturning of old values and their immediate substitution by new, a dramatic change whose beginning can be precisely dated. It appears that this apocalyptic element of comparison is unreal, and this has led many to criticise the use or relevance of the term at all. But if one looks, from the standpoint of the second half of the twentieth century, at the changes wrought by the French Revolution and by the British Industrial Revolution, the comparison again becomes valid. The eighteenth century in Britain saw changes which produced similar long-term political effects to those created by the bloody revolution in France. There was as much, if not more, of a difference between pre- and post-industrial Britain as between pre- and post-revolutionary France. The watershed between the essentially medieval and the essentially modern economy, if not marked by a sharp ridge, was nevertheless a real one.

Britain was the first country in the world to undergo an industrial transformation of its national economy. This transformation occurred spontaneously, without any outside direction, without any conscious policy of stimulating industrial growth, without any momentum being directly imparted through taxation or through capital being made available. Indeed the state showed no interest whatsoever in promoting industrial activity or encouraging new skills. The revolution just happened, and we can only surmise at the reasons why.

It is unlikely that any *single* factor brought the economy to this point of take-off. A whole complex of interrelated movements, some with their origins as far back as the Middle Ages, reacted with each other to produce a situation in which the economy 'went critical' in the second half of the eighteenth century. Once the chain reaction had begun, growth became more or less automatic. What factors were involved? There were the direct economic forces of population growth, of agricultural improvement, of increasing trade and the growth of markets, of capital accumulation and the development of a flexible banking system, of the breakdown of medieval conditions of control and regulation and their supersession by those of competition, of business enterprise, of improvements in communication and of technological innovation. There must also have been many subtler influences resulting from deep-seated stirrings within society—changes in

religion and conditions of religious tolerance, scientific advances and a political situation in which government, if not giving active support to industrial enterprise, was at least acquiescent. Conditions of relative stability in Britain must also have been important. The country became a haven for political and religious refugees, many of whom brought with them manufacturing techniques and the enterprise necessary to put those techniques into practice. There were also natural advantages in the availability and, in some cases more importantly, the close proximity to each other of raw materials such as good quality sheep pasture, iron ore and coking coal and consistently flowing streams for power. Also to be considered must be those entirely fortuitous occurrences such as the succession of good harvests in the 1730s, which contributed to general prosperity and the creation of surpluses, and thus helped to generate a climate within which the other components of change could interact more satisfactorily.

We are not here primarily concerned with the causes of the Industrial Revolution but more with the fact of its occurrence and its physical effects on society and the landscape. Nevertheless it is worthwhile looking a little deeper into causes in order to gain some understanding of the enormous changes brought about by industrialisation, and to follow them through into the period of the Industrial Revolution itself. Firstly, population. This was increasing at the end of the seventeenth century in parallel with a gradual increase in food supplies. The population of England in 1700 was probably slightly more than 6 millions; it had increased to 6½ millions by about 1750 and then started climbing rapidly to reach just over 9 millions by 1801, the date of the first census. Economic expansion in the first half of the eighteenth century was facilitated by two decades of good harvests after 1730. The increase of real incomes provided a market incentive, a stimulus to producers of goods and imported commodities. The increase in foreign trade, in addition to the new home demand, was opening up colonial markets to home manufacturers. Population growth, therefore, was only one of the features of this first phase of industrial growth. But was it in fact a cause or a consequence of the economic changes? The dramatic growth rate after 1770 may have been a result of the rise in birth rate, itself resulting from the demand for labour leading to earlier marriage and therefore earlier parenthood. On the other hand social and economic factors such as improved food supply and better clothing and housing substantially reduced the death

rate, a trend accentuated by the beginnings of smallpox inoculation and improved medical knowledge applied to the feeding of children. In the middle of the eighteenth century, however, the initial growth took place before the period of rapid economic expansion and must therefore be regarded as one of its causes. What is also certain is that once the balance had been tipped in favour of self-sustained growth, an increased number of consumers and workers became a necessary condition of further industrially based economic advance.

Population growth was by no means evenly distributed and, once industrialisation had got under way, the effects of a reorientation of the population axis were, in terms of landscape changes, of very great importance. Fig 1 shows population distributions at the beginning and end of the eighteenth century. In 1700 the population was thickest along a line running south-west to north-east through the fat agricultural lands of lowland England. By 1800 that axis had been turned through 90 degrees and there it still lies today. The areas in which industry was centred saw a more rapid population growth than predominantly rural counties, which, although in a few small areas suffering a decline, continued to grow but at a less rapid rate. The growth in the new industrial areas was not generated entirely from within, there being massive migrations from the countryside.

By 1831 about one-third of England's population was engaged in industry, a proportion, but not of course a total number, which remained more or less stable throughout the rest of the century. The 'new population' was predominantly concentrated in towns and cities in the Midlands and North. Previously towns, particularly in lowland England, had been evenly spread nodal points with primarily market functions. (The area of densest population on the 1700 map, Fig 1, still has this essential character today.) After the axis had shifted, enormous urban concentrations grew up. London had always been much larger than all other towns. In 1800 it had nearly 900,000 inhabitants but there were only fourteen other towns with populations of over 20,000. By 1851 London had a population of over 2½ millions; by then, however, there were fifty-four towns and cities with a population between 20,000 and 100,000, and seven (Birmingham, Bradford, Bristol, Leeds, Liverpool, Manchester and Sheffield) with over 100,000 inhabitants. Of these only Bristol lay outside the new axial belt of economic and population growth.

# DISTRIBUTION OF POPULATION IN ENGLAND AND WALES

BY COUNTIES

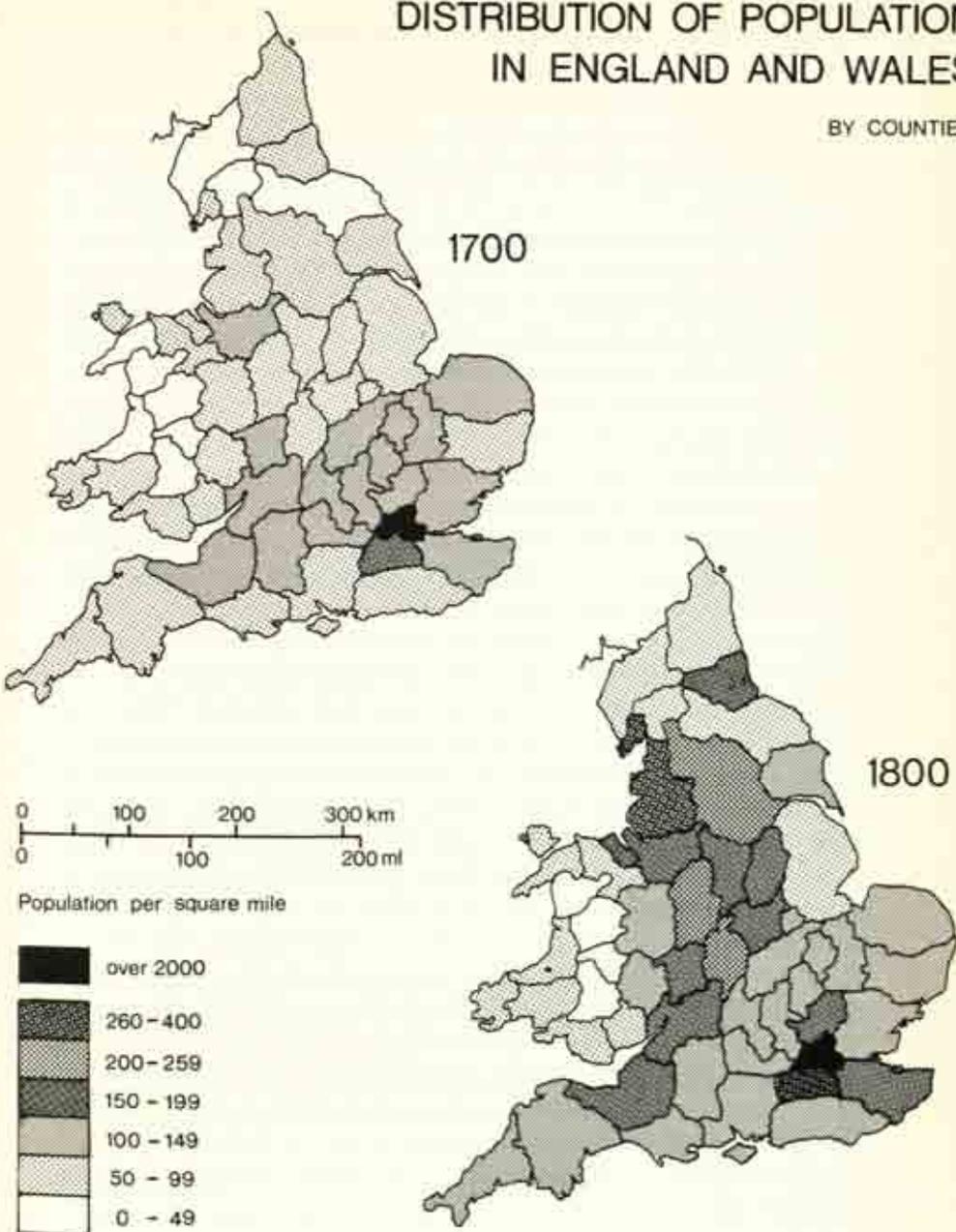


Fig 1

There were two major factors in the increased agricultural output which went hand in hand with population growth throughout the eighteenth century. The first was enclosure, the second the superior methods of husbandry and of farming technology introduced by the great improvers. Both were closely interlocked, enclosure being the essential prerequisite for the introduction of new techniques. Much of the new equipment introduced after 1750 would have been useless on the old strips of the open-field system. Similarly, introduction of new crops or rotations and methods of animal breeding was out of the question in an essentially feudal agricultural system where custom, tradition and the standards of the poorest quality cultivator were dominant. In other European countries, where enclosure lagged behind Britain, the introduction of new methods was slower and confined to large estate farms. Enclosure then was the largest single movement affecting land use, and therefore output, because it made possible all other innovations. Enclosure increased the cultivable area by eliminating the commons and wastelands which had been essential rough grazing areas under the old system, and bringing them into active agricultural use on the regular sequential basis of the new rotation farming.

By 1750 perhaps half of England (and the open-field system was confined almost entirely to lowland England) was enclosed. In some areas open fields had never existed and in others they had been long outmoded. These areas lay around the edges of a core of unenclosed land with counties such as Northamptonshire at its centre. The south-west and the grass counties of the Welsh marches, the north-west and the south-eastern counties of Suffolk, Essex, Sussex and Kent were all substantially or completely enclosed by the middle of the century. For the remainder of England the major period of the enclosure movement was 1760-1815, when most enclosures, in contrast to the earlier period, were made as the result of Parliamentary awards. Over 1,000 Acts covering 7 million acres were passed between 1760 and 1800, with a further 800 by 1815. The first batch related generally to areas where grazing and cattle-fattening were the dominant forms of husbandry, and the latter mainly to arable land, whose enclosure was stimulated mainly by the rise of grain prices during the Napoleonic wars. These enclosures took in most of the remaining open fields. Today one or two areas still survive—Laxton in Nottinghamshire and Portland in Dorset, for example—where traditional practices are continued.

The sequence of events, therefore, was firstly the introduction of new theories and new crops in the seventeenth century, such as Townshend's turnip-fed stock, followed by the first stages of mechanisation promulgated by men like Jethro Tull. Diffusion of these ideas on a wide scale came later with enclosure and with the increased demand resulting from a growing population, particularly in towns.

Capital availability was significant to this 'agricultural revolution', but it was much more important to the new industrial entrepreneurs. The early growth of banks, not only in London but in country areas too, made short-term credit available for agriculture, industry and transport. By 1780, when there were 100 banks outside London, a network of credit extended throughout the country, facilitating the transfer of funds, the settling of debts and the obtaining of cash. By the late 1820s there were 554 country banks, after which numbers declined as they were absorbed into the big joint-stock banks with their networks of branches.

The banks did not, however, provide the key to the much larger quantities of capital required by industrialists to launch their enterprises. Most manufacturing industry was in the hands of family businesses or partnerships in the middle of the eighteenth century. This was to some extent inevitable, as without the protection of Limited Liabilities Acts (which did not come in until 1855-62) each partner in an unincorporated business was totally liable for its debts, however little he had invested in it. The 'South Sea Bubble' Act of 1720 had limited the number of shareholders to eight, so unless the company was set up by Act of Parliament, as a few large enterprises like canals and later railways were, the corporate responsibilities carried by those in industry were considerable. Partners tended, therefore, to be found within the framework of a family or a church where the ties of trust were strongest. With some sectors of the community, such as the Quakers, family and faith were often inextricably interwoven, and the fact that they were debarred from political positions made them turn to those avenues which were open to them—industry and commerce.

Most of the capital that financed the early phase of the Industrial Revolution came from two main sources. Firstly, there was accumulated capital, the result of the more or less continuous expansion in the economy in the middle years of the eighteenth century before industrialisation really got under way. Accumulation of capital in the hands of landowners and

merchants, for example, was considerable, and much of this found its way into industry, often industry within the family network. 'Outside' capital was the other source, the investment by many sectors of the community of relatively small sums in an industrial enterprise. The landed aristocracy, traditional holders of wealth, were frequently energetic investors and in many cases financed new industries directly themselves, but the savings of the professional classes, craftsmen and working men, often through their friendly societies, found its way into industry also. One of the great strengths of industry in Britain, and conversely one of the greatest heartaches when a company failed, was the broad base of industrial investment, seen at its extreme in the capitalisation of the railways.

Another important factor was that, for many industrial enterprises, the cost of the initial fixed assets was relatively low, so it was possible to start on a small scale and expand almost entirely on the reinvestment of profits. Technology was relatively simple and the cost of buildings and equipment not inordinately large. Given technical expertise in the process, perhaps the most valuable single asset in setting up a new manufacturing firm, it was not too difficult to make a start. The number of skilled craftsmen who left established organisations to set up on their own with no more than the traditional 'life's savings' was considerable, and an almost typical feature of some sections of industry.

We have mentioned population increase as an important factor, representing both a new source of labour and also a new market for manufactured goods. Of increasing significance throughout the eighteenth century also was the development of Britain's overseas trading connections. In the 1570s England had one major export commodity in woollen cloth, which accounted for some 80 per cent of the value of her trade, nearly all of which was with North Sea ports or the Atlantic seaboard of Europe. By the 1770s she had a wide range of manufactured exports, of which wool still constituted the largest, and a big re-export trade in colonial and export goods. Her trade extended not only throughout Europe but to America, Africa, India and China. Indeed the century after about 1660 has been titled the period of the 'Commercial Revolution', so important was it to the development of merchant organisation, to capital accumulation and investment and to the market opportunities which were provided to the new industries.

Firstly, the collapse of Antwerp in the late sixteenth century as the entrepot

for Europe led, after a period of initial uncertainty, to English merchants having to seek their own connections, by sea, with their European markets. Because the system of money transfer by bills of exchange was not developed in these new markets, merchants were bringing back materials for which there was initially no immediate home sale, including coarse linens, sugar, drugs, cotton, silk, flax, hemp and timber. In consequence, a thriving re-export business developed at the beginning of the seventeenth century, but it gradually declined as the home market became more sophisticated and as new, often port-located, industries grew up; these industries sometimes used immigrant labour, as with silk weaving, to absorb these readily available raw materials. London began to assume the position once held by Antwerp, becoming the base for merchants and, as the eighteenth century progressed, for financiers, bankers, insurance companies and shipping underwriters.

Before 1640 there was little home demand for the products resulting from Britain's small but increasing long-distance trade with Asia and America, which was beginning to thrive on the re-export business. Indeed Europe, by far the largest single market until well into the nineteenth century, had great attractions to Britain, whose direct access to distant ports enabled her to re-export directly or process and then re-export the imports resulting from this trade. The notorious triangular trade with West Africa and the Americas developed in this way, with weapons and 'toys' from Britain being exchanged for slaves in West Africa, and those slaves exchanged for sugar, tobacco, dyestuffs or hardwood in the West Indies. These imports were frequently processed in London, Bristol or Glasgow and then re-exported to Europe. As home demand grew, however, the need to re-export died away, and completely new imports provided the basis for industrial growth. The Lancashire fustian industry and the Nottinghamshire cotton hosiery trade were both based initially on imported Indian cotton. In a city like Bristol a high proportion of the considerable industrial activity became based on imported raw materials for eventual home consumption. Sugar refining, sherry blending and wine bottling, chocolate making, tobacco processing, logwood dye manufacture, even cotton spinning and weaving for a short time, all grew up in or around Bristol because it was the place of import and thus the logical break-of-bulk point at which to carry out processing.

By the latter part of the eighteenth century the 'Commercial Revolution' of the previous 100 years had provided Britain with trading connections throughout the world, had made London the financial and mercantile centre of Europe and was producing an accumulation of capital much of which was finding its way into industrial investment. Much of the profit from trade went into mining and manufacturing industry. Bristol and London merchants helped finance coalmining and ironmaking in South Wales, and Glasgow and Liverpool merchants put capital into the cotton industries of Scotland and Lancashire respectively.

We have now looked at a number of the major factors which combined to trigger off the Industrial Revolution. One classic prerequisite, however, of the British Industrial Revolution, although not necessarily of others that have come since, remains to be examined—the role of technological innovation. The development of new technologies was such a remarkable and obvious feature of the Industrial Revolution that many people have regarded it as the primary cause. To them the Industrial Revolution was a technological revolution in which new manufacturing machines were driven by new sources of power in new large-scale units called factories. So enthusiastic was Samuel Smiles about this thesis that he wrote in his *Lives of the Engineers*, 'Our engineers may be regarded in some measure as the makers of modern civilization . . .', and then went on to pose the question, 'Are not the men who made the motive power of the country, and immensely increased its productive strength, the men above all others who have tended to make the country what it is?' To some extent Smiles was right, but for new inventions in technology to be relevant a whole range of other factors, such as those we have already considered, had to be there too.

Given these favourable base conditions, there also had to be a will to generate new ideas and a climate in which new ideas, if not universally acceptable, could find currency amongst other enthusiasts, who would implement, multiply and perhaps improve upon them. That climate was growing in Britain throughout the latter part of the seventeenth century and the whole of the eighteenth in the form of a new class of bourgeoisie, intelligent but not always educated, well-to-do but not always wealthy, articulate but not always cultured, who owned property, manipulated money or followed one of the growing professions. These were not often the people who created the new ideas, but they were the ones who were

prepared to listen, who were capable of understanding and who were prepared to offer backing.

Another requirement of technological innovation, although not necessarily of the invention which might precede it, was need. 'Necessity is the mother of invention' is one of those catchphrases which provides a surprising amount of food for thought. The steam engines of Savery and then of Newcomen were developed because of the specific problem of draining mines and, at a much later date, Watt was almost forcibly directed into developing a *rotative* steam engine capable of driving rotating machinery because Boulton appreciated that the need was there. In the United States a different sort of necessity in the middle of the nineteenth century resulted in the development of sophisticated production machinery as a means of maintaining and increasing output in the face of an acute shortage of skilled manpower. The finished product was not necessarily any better, but the technique of making it certainly was.

Some inventions relied on intellectual genius, others on the systematic investigation of possible alternatives until the right answer came up, and others still required some almost fortuitous outside factor to intervene. Abraham Darby I was undoubtedly aware of the social and economic need for an alternative fuel to charcoal for iron smelting, although how far that need was being directly felt in Coalbrookdale in 1709 is difficult to assess. The geological accident of the eminent suitability of the Coalbrookdale 'Clod' coal for making coke for smelting purposes must be borne in mind when measuring the significance of the coke smelting technique which he perfected. Over a century and a half later another attempt to find an alternative fuel, in this case the substitution of coal for coke in locomotive fireboxes, was tortuously pursued for years, with innumerable patents and experimental designs, before the perfection of the brick arch in 1859 allowed coal to be burnt successfully. Successful invention and innovation demand a number of prerequisites — a climate of acceptability, perhaps the one feature unique in Britain in the eighteenth century; an obvious need; and an element of genius, perseverance or opportunism, or possibly all three.

Undoubtedly the cumulative effect of innovation in technology was beginning to be felt on a large scale by the end of the eighteenth century. Using the simple indicator of patents, of the 2,600 for the whole of the century, more than half were registered after 1780. We must, however,

allow innovation in technology no more than its proper importance, for although the products of many of the great inventive engineers provide much of the inspiration for the study of industrial archaeology, they had relevance only when combined with entrepreneurial ability and the effective organisation of capital, the market and the methods of production. Thomas Telford was arguably an organiser of men first and foremost and an engineer second. The canal network owed little or nothing to advanced technology but much more to the organisation of large numbers of men and the mobilisation of capital. In the textile industry a whole range of closely interlinked inventions provided the baseline from which the industry could free itself from its medieval shackles, though it was in the factory, which was primarily a symbol of organisation rather than technology, that the potential of these inventions was realised. The factory system was being exploited for its organisational advantages by people like Benjamin Gott in Leeds, for example, before the advantages of power applied to a multiplicity of machines were fully realised.

If we accept that the Industrial Revolution had its beginning in the eighteenth century, when, if at all, did it end? Application of the self-sustaining growth theory has suggested that 1830 was the terminal date, the point by which the chain reaction had got going and the economy was in a state of more or less automatic and continuous growth. Certainly some industries had undergone a complete technological change by that date: the textile industry was largely mechanised and power-driven; and the iron industry, where both cast iron and wrought iron were available in quantity, was using coal instead of charcoal and the puddling furnace instead of the finery and chafery. Canals networked the country and, although not representing any major technological breakthrough, they were an essential ingredient of industrial growth both as an internal transport system and as a means of getting commodities to and from the ports. If 'revolution' in this context only means the period of change from one style of economy to another, the period when growth rate in the economy accelerated, then the choice of 1830 has some validity; but if continuity of growth, particularly growth based on new technologies and new industries, is included, that date is clearly of no significance at all. Indeed, if we assume continued growth based on technology and industry, we must seriously ask ourselves whether we are not still in the period of the Industrial Revolution.

The industrial archaeologist needs to take a much broader approach. He is looking primarily at the period of industrialisation beginning in the eighteenth century, but he has to look back beyond that date to find the antecedents, to explain the evolution of the waterwheel, to understand the transfer from charcoal smelting to coke smelting, to discover the scientific ground rules which had been established in the sixteenth century and were implicit in the development of the atmospheric steam engine. Having accepted that industrialisation is under way he must apply archaeological rather than historical criteria when trying to settle how far he goes chronologically. The period of take-off as seen by the economic historian is quite unsatisfactory for the industrial archaeologist, who is looking at the remains of industrial activity over a much longer period. To him the obsolescence of a process or of a social or economic demand for an industry must form the terminal criteria; absolute date is almost irrelevant.

Let us consider 1830 as a terminal date in relation to the whole period of industrialisation. Railways were only just beginning to be accepted, the Liverpool & Manchester Railway opening in that year. The shipping industry was still largely traditional and pre-industrial in character, although steam power was beginning to be applied. There were no iron ships, let alone steel ones. Cheap steel was still more than a quarter of a century away, with Henry Bessemer and the converter. Michael Faraday, in 1831, produced a continuous electric current, the beginnings of one of the most fundamental developments in power for industry of the latter part of the century. These events and many that have come since are the valid concern of the industrial archaeologist.

Let us examine the magnitude of the effects of industrialisation on Britain. The economic consequences are measurable and staggering in their scale. National income in England and Wales was £130m in 1770; in Great Britain as a whole in 1800 it was £230m, in 1830 £350m and in 1850 £525m. This shows a doubling of average income per head. By the end of the nineteenth century the national income had increased by a factor of about fourteen and real income per head had roughly quadrupled. Despite the traditionally pessimistic view of the horrors of industrialisation seen in terms of poverty, of appalling living conditions and of periodic heavy unemployment, the real wages of the majority of workers in British industry were rising and their living and working conditions, *on average*, were improving.

The statistics of growth for individual industries provide some of the most startling indicators of the effects of industrial activity. There were less than twenty blast furnaces in 1760. By 1790 this figure had increased to over eighty and in 1797 England became for the first time an exporter of iron and iron goods. There were 177 blast furnaces in 1805, 372 in 1830 and 655 in 1852. The majority were coke-fired after 1800. Pig iron output increased from 30,000 tons in 1700 to 250,000 tons by 1805, 650,000 by 1830 and 2 million tons by mid-century. In the cotton industry growth was still more spectacular, largely as the result of the improvements made in machine spinning by James Hargreaves, Richard Arkwright and Samuel Crompton with the introduction of the jenny, the water frame and the mule respectively. Import of raw cotton, which was less than 8 million lb per year in 1780 had risen to over 25 million lb by 1790, 37.5 million lb by 1800 and nearly 60 million lb in 1805. The 100 million lb point was reached in 1815, 250 million lb in 1830 and 620 million in 1850. The number of cotton spindles increased similarly from less than 2 million in 1780 to 21 million by the middle of the nineteenth century. Mechanisation in weaving of cloth developed slightly later but, once under way, the results in terms of production were no less remarkable. With hardly any power looms in 1820 the industry grew to have 50,000 in 1830 and 250,000 in 1850. The cotton industry as a whole employed about half a million people in 1830, of whom about half were working in factories. Over 50 per cent of total production was exported, representing in value about 40 per cent of all British exports.

'Good roads, canals and navigable rivers, by diminishing the expense of carriage, put the remote parts of the country nearly on a level with those in the neighbourhood of the town; they are, upon that account, the greatest of all improvements.' So wrote Adam Smith (1723-90) in the late eighteenth century and, without doubt, good communications provided the basis for the factory growth of the iron, the cotton, and many other industries. In 1750 there were about 1,000 miles of navigable river in England. In the following century over 4,000 miles of canals had been built, linking the main industrial areas with the rivers, ports and coalfields. What is more significant, however, is that nearly three-quarters of that canal mileage had been completed by 1800, thus providing, at the beginning of the Industrial Revolution period, the consolidation and unification of the English market that was so essential for growth. The significance of railways was still greater,

and between 1840 and 1850 5,000 route miles were built, more than the whole of the country's total canal mileage. The effects of railways were felt in many fields beyond those connected directly with the transport of goods. Besides reducing the time and cost of travel and extending the communications system over a wider area than that covered by the canal network, the railways increased the mobility of labour and further encouraged concentrations of population, gave an enormous boost to the iron and engineering industries with their demand for rails and locomotives and were largely responsible for the new and widespread habit of investment in industry. By 1850, for the first time ever, a nation was devoting at least 10 per cent of its total income to capital accumulation in one form or another.

In addition to communications, coal was essential to the development of industry, and the discovery of ways of using coal where once wood had been essential was a decisive technological factor in allowing many industries to 'take off'. The use of coal to generate steam removed industry still further from its reliance on nature by reducing dependence on water power. As early as the beginning of the eighteenth century England had been unique in Europe for its large consumption of coal, probably then about 3 million tons per year. By 1800 it had grown to 10 million tons, almost entirely as the result of increased industrial activity. Coal (in the form of coke) began to replace charcoal for iron smelting and later for puddling of wrought iron, it was the primary fuel of the rapidly expanding brick industry and, of ever-increasing importance, it powered the new steam engines. By 1800 there were perhaps 1,000 steam engines in use in England, the large majority pumping water from rivers. About 250, however, were driving machines in the cotton industry and, as the nineteenth century progressed, steam engines increasingly replaced human, animal, wind and water power. Thus, by 1838 the cotton industry was using 46,000 steam hp and the woollen industry 17,000. By 1850 the textile industry as a whole was using nearly 100,000 steam-generated hp. All of this was provided by coal, the first raw material in history to be measured in millions of tons. From 10 million tons produced in 1800 output grew to 25 million tons in 1830 and 50 million tons in 1850.

These statistical indices of growth tell only a small part of the story of industrial development in Britain during the eighteenth and nineteenth centuries, covering up at a single sweep the subtleties of social change and

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enormities of social cost which can never be fully documented. The remains of the landscape changes wrought by industry are still there to be seen and studied by the industrial archaeologist, but the effects on ordinary people of those changes, the most radical changes of environment which any society had ever experienced, can only be pieced together from fragmentary evidence. Much of this evidence results from the observations of outsiders not directly involved themselves in industrial activity—in the diaries of travellers, the reports of commissions of enquiry, and the essays of political writers, all of which reflect to a greater or lesser extent the particular axe which their authors had to grind. Moreover, those artists who did not regard it as beneath their dignity to portray industrial subjects, provide a startling and perhaps slightly less biased insight into the nature of Industrial Revolution Britain. But despite these conscious attempts at documentation, objective or not, the real magnitude of the change in the way of life of the ordinary man as industrialisation gathered momentum and eventually became a tide carrying all before it can never be assessed. He rarely documented himself or his doings, although his songs have sometimes survived, and his artefacts—few at the time—are almost non-existent today. Only the houses in which he lived and the factories in which he worked provide today a widespread, tangible and emotive source of evidence which can be analysed, in association with oral and documentary sources, to gain some insight into his way of life, his attitudes and aspirations. The industrial landscape is the *place* where it all happened and as such represents one of the closest contacts we have with the people who made it happen.

### 3 Wind and Water Power

THE twentieth century has witnessed the virtual extinction in Britain of the use of wind and water power for commercial purposes. Man's earliest engines, the first mechanisms to release him from the slow and tedious labour of grinding corn by hand, have almost ceased working. The crafts of milling and millwrighting, passed on without interruption through many centuries, have also now almost disappeared, and only our nostalgia and the respect in which we hold these reminders of the beginnings of civilisation have led us to preserve both windmills and watermills in considerable numbers. A few of them are still working, and in this way we can keep alive their techniques of operation.

The earliest application of the power of water was perhaps in the first century BC, probably in Greece. The earliest known record of a watermill in England is much later, in a charter granted in AD 762 by King Ethelbert of Kent to the owners of a monastic mill east of Dover. Wind power on the other hand is of more recent usage, and although early windmills were known in Persia and Asia Minor well before the tenth century AD, they do not seem to have been used in north-west Europe until the twelfth century. The earliest known in England appears in a documentary reference of AD 1158 recording a corn mill in the village of Weedley in Yorkshire. It is just conceivable that such early English mills, which are recognisable from illustrations as post mills, were the first of their type, for there was a noticeable spread of them eastward through Europe during the thirteenth century, suggesting that they may have developed quite independently of the primitive windmills of Persia. If this is so, it represents a significant reversal of the prevailing flow of ideas from the East, and may be the first example of West European technology to find widespread use.

Wind power had nothing like the impact water had on the growth of industrialisation, for while the waterwheel developed into a reliable, controllable and powerful prime mover for driving a wide variety of machinery, often in very large factories, the windmill kept very much to its traditional role of grinding corn and draining low-lying land. Considerable efforts were

made to improve its efficiency, but the inherent unreliability of the wind prevented it being used to drive manufacturing equipment where regular hours of work and continuity of output were essential. It is worthwhile therefore considering the windmill first, as the story of its evolution and decline is outside the mainstream of events that led up to and carried forward the large-scale industrialisation of Britain during the eighteenth and nineteenth centuries. Indeed the improvements made to the windmill, all of which came after the waterwheel and steam engine were well established, may be regarded as products of the new technology, used to increase the efficiency and reliability of existing capital equipment in an area where investment potential was low.

The question of availability of capital was an important one, as a major obstacle to the use of power during the sixteenth and seventeenth centuries had been cost, a factor which remained relevant in some agricultural areas almost to the end of the nineteenth century. The capital involved in a windmill or watermill relative to the power generated was fairly high, so there was a tendency to perpetuate man- or, more frequently, animal-powered equipment. At a later date the same factors militated in favour of the waterwheel when it came to the question of its replacement by steam power. A number of disused horse-powered mechanisms still survive, mainly those employed for driving farm machinery, but also a few used to raise coal or water. More often the building alone remains. In a county like Durham, where horse gins were exceptionally numerous, a typical feature of many of the farms is an octagonal building with a pointed roof; such buildings once housed a horse walking endlessly around a central spindle coupled by drive shafts to machinery.

#### WINDMILLS

The earliest type of windmill in England was the post mill (Plate 1); its body, which contained the machinery and on which the sails were mounted, stood on a central post about which it could be rotated to bring the sails into the wind. The absence of a dominant wind in Britain meant that the simpler type of uni-directional mill which originated in east and south Europe could not be adopted. None of these medieval mills survive, but illustrations are profuse, all showing the post mill in a form almost identical to those existing today. St Margaret's Church, King's Lynn,



1 A post mill: Drinkstone,  
Suffolk

Norfolk (124/TF 617197), has a mid-fourteenth century memorial brass depicting a post mill, and representations carved in wood can be seen on a fifteenth-century misericord in Bristol Cathedral (156/ST 584726) and on a sixteenth-century bench end in the parish church of Bishops Lydeard, Somerset (164/ST 168298). This last example clearly shows the sails in their earliest form, symmetrically mounted on the stocks.

The post mill, even today, is remarkable for its technical ingenuity, representing one of the medieval carpenter's greatest achievements in design and construction. It consisted of a small timber-framed building designed to balance and pivot on a single vertical post. The post was held in position by diagonal quarter bars resting on a pair of oak crosstrees that were arranged

at right-angles to each other and provided the base for the whole structure. The weight of the body or 'buck' of the mill was borne by a transverse beam, the 'crown tree', which rested across the top of the post and was free to rotate on it. Originally an oak pintle would have provided the centre, but later an iron gudgeon was usually fitted. The end of the crown tree carried the frame of the mill, mortice and tenon jointed and dowelled together, with timber diagonal braces providing rigidity. Very little iron was used. From the back of the buck projected a tail pole that was used like a tiller to orient the mill towards the wind. The pole was moored to wooden posts arranged around the circumference of the circle described by its tip. In some cases, such as in Chillenden Mill, Kent (173/TR 268543), a wheel on the end of the tail pole helped support some of the weight of the tail ladder.

Early post mills, like Bourn Mill, Cambridgeshire (134/TL 312580), had a simple pitched roof but most have the familiar curved shape, providing greater clearance for the brake wheel, and are generally clad in horizontal weatherboarding. From the eighteenth century it became common to enclose the underframe in a roundhouse, usually built of brick, with a conical roof. This provided useful storage and protected the frame timbers from the weather. Holton Mill, Suffolk (137/TM 402776), has a very typical roundhouse.

The earliest surviving post mills in England probably date from the beginning of the seventeenth century, when the first dated inscriptions occur; the date 1627 carved on a timber of Pitstone Mill, Bucks (159/SP 945157), is perhaps the oldest. By this time a new type of mill had been introduced from Europe—the tower mill, which possibly had its origins in the fifteenth century. In this type of mill the grinding machinery was mounted in a fixed stone or masonry tower, circular in plan and usually conical in elevation. On top of the tower was a movable cap on which the windshaft and sails were mounted. Only the cap had to be turned to bring the sails into the wind, and the drive from the windshaft was transmitted to the millstones mounted in the tower by a central vertical spindle, the main shaft. The early towers were squat and cylindrical, like those still to be seen in Spain. In Britain the type has only survived in Somerset where Ashton Mill, Chapel Allerton (165/ST 414504), is the last complete example. It is maintained by Bristol City Museum and is open to the public. The cap was usually conical and covered with thatch or tiles. A thatched cap survives, also in Somerset,

at High Ham Mill (165/ST 433305).

The first tower mills had tail poles for rotating the cap and this effectively limited their height. Similarly the cylindrical shape of the tower was dictated by the angle of the windshaft, which was initially horizontal. Later the windshaft was inclined, balancing the weight of the sails and reducing the likelihood of them being lifted out of the mill by a freak wind catching them from behind. Mill towers could then be conical in shape, and much more satisfying structurally (Fig 2). Not all were circular in plan: the tower of Wheatley Mill, Oxfordshire (158/SP 589052), is octagonal and that at West Wittering, Sussex (181/SZ 797972), is circular, though standing on an octagonal base.

The third basic type of windmill in England was the smock mill (Plate 2), its name allegedly derived from its similarity in appearance to a man wearing a smock. It was basically a tower mill, the tower being built of timber, usually on an octagonal plan. At each corner a 'cant post' extended the full height of the mill, its foot resting on a timber cill, its top providing support for the circular curb on which the cap rotated. The sides between the cant posts had horizontal and diagonal framing and the whole was clad in weatherboards, often painted white. The cill was normally set on a brickwork plinth to provide a firm foundation, but in the nineteenth century brick bases as high as one or even two storeys became common and the height of the mill was no longer restricted by the availability of long timbers for the cant posts. The Willingham smock mill in Cambridgeshire (135/TL 404697) and the very fine Cranbrook Mill, Kent (172/TQ 779359), the tallest mill in England, are both of this type. The oldest English smock mill is at Lacey Green, Buckinghamshire (159/SP 819009). It was originally erected at Chesham about 1650 and moved to its present site in 1821, and although substantially complete, it is now in poor condition. The last mill to be built in England was also a smock mill, in 1929 at St Margaret's Bay, Kent (173/TR 363435).

Both tower and smock mills were surmounted by timber-framed caps of a wide variety of shapes. The cap was carried on horizontal beams that supported the weight of the sails and windshaft. It revolved on a circular curb of timber forming the top of the tower. In early mills this was greased and the cap simply slid on the smooth surface—a 'dead curb'—but later hardwood or iron rollers were fitted to form a 'live curb'. At the front of the

## TOWER MILL

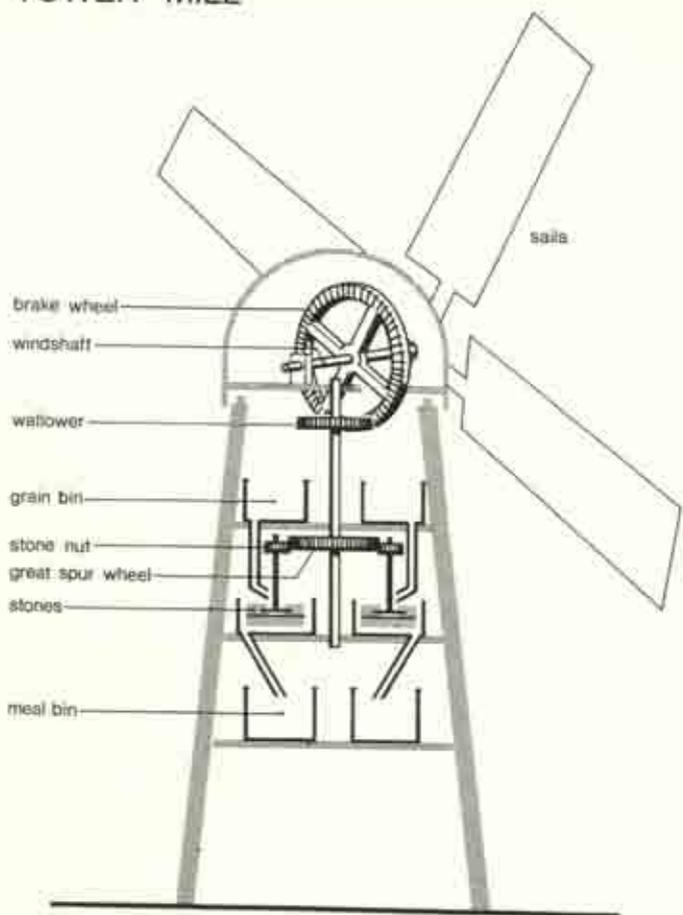


Fig 2

cap the 'weather' or 'breast' beam carried the neck journal of the windshaft, the other end of which was mounted in a thrust bearing on the tail beam. The distinctive shapes of windmill caps seem to have some regional variation, although how far these are significant is difficult to assess. The simplest form is a triangular gable, as at Bembridge, Isle of Wight (180/SZ 640875), an eighteenth-century stone tower mill, cement-rendered on its weather side.



2 A smock mill: Great Thurlow, Suffolk

In Kent, Essex, Surrey and Sussex caps are shaped like small post mills with curved gables. Notable examples are at Herne (173/TR 184665) and Cranbrook in Kent. A variation of this type but curved in both planes to conform more to the plan of the top of the tower is the boat-shaped cap found in the eastern counties and exemplified by Gibraltar Mill, Great Bardfield, Essex (148/TL 681308). Simple cones do not occur in England, as they do on the continent, but domes have a wide distribution, ranging from Polegate (183/TQ 581041) and Selsey (181/SZ 843933) in Sussex to West Wratting Cambridgeshire (148/TL 604510), and Wilton (167/SU 276617) in Wiltshire. Far and away the most exotic are the ogee mill caps of Lincolnshire, which are made all the more prominent by the tall brick towers they usually

surmount. They occur throughout eastern England, however, with subtle variations in shape from one area to another. Some have slightly flared bases, as at Burwell, Cambridgeshire (135/TL 590665), while others achieve an almost onion shape. Some are boarded and covered in painted canvas, and others have sheet copper cladding that has often weathered green. Almost all have finials, usually in the form of a ball, though occasionally an acorn style is used.

Early windmills had simple wooden frames on which the canvas sails were spread. These frames were mounted symmetrically on stout tapering beams known as stocks, which were crossed at right-angles and morticed through the end of the windshaft. Lateral support was provided by short 'sail bars', rather like the rungs of a ladder, which were connected at their outer ends by light longitudinal 'hemlaths'. By the eighteenth century the symmetrical sail had given way to the 'common sail' seen on many mills today, in which the whole surface area was on the trailing side of the stock. A narrow windboard along the leading edge directed the air flow on to the cloth which was arranged on the front of the sail frame. 'Pointing lines' secured the canvas and were used by the miller in reefing the sails to suit the speed of the wind. As mills grew larger, it became common to construct the sails as separate units on long tapered 'whips' which were strapped and bolted to the stocks. A major point of weakness on early mills was the joint where the stocks were morticed through the windshaft, but the introduction of cast iron provided something of a solution to the problem, the end of the shaft being replaced by a massive casting known as a 'canister' or poll end into which the stocks were secured by wedges.

The common sail was light, simple and aerodynamically fairly efficient but it suffered a major disadvantage in that a change in wind speed necessitated stopping the mill and re-arranging the canvas a sail at a time. In 1772 a Scottish millwright, Andrew Meikle of East Lothian, invented a sail composed of shutters arranged like a Venetian blind and linked by a connecting rod or shutter bar which ran the length of the sail. An adjustable spring at the windshaft end maintained the shutters in the closed position under normal wind pressure but allowed them to open and spill air during gusts. Spring sails controlled by elliptic leaf springs can be seen on Outwood Mill, Surrey (170/TQ 327456), and Chillenden Mill, Kent (173/TR 268543). The miller still had to stop the mill to make adjustments to the spring tension but the

automatic regulation was a valuable benefit. In 1789 a Captain Stephen Hooper introduced a roller reefing gear similar to that used on sailing craft but it found little favour.

The most significant step forward in sail design came in 1807 when William Cubitt's patent sail appeared. For the first time in nearly 1,000 years the windmill had become a controllable machine in which the sails could be matched to the wind speed while they rotated. Patent sails retained Meikle's shutters and shutter bars but at the centre the springs were replaced by bell-cranks connected to an iron 'spider'. The spider was mounted on an iron 'striking rod' which passed through the hollow windshaft and emerged at the back of the mill where it terminated in a rack-and-pinion drive controlled by an endless chain hanging down to the ground. Moving the striking rod backwards and forwards operated the shutters. A fully automatic control was achieved by hanging weights on the chain which held the shutters closed against the air pressure but still allowed spillage if wind speed increased or conditions were gusty. Patent sails are found on, for example, Cranbrook Mill and Herne Mill, Kent (173/TR 184665), and at West Wratting in Cambridgeshire (148/TL 604510) the mill combines two patent with two common sails.

Although most mills had four sails, some were built with five, six and even eight in an attempt to increase sail area and efficiency. Five sails were least common, as the loss of a sail resulted in imbalance and stoppage until a replacement could be fitted. Three five-sail mills still exist, all in Lincolnshire: Maud Foster Mill, Boston (Plate 3, 114/TF 333447), Burgh-le-Marsh (114/TF 504650) and Alford (105/TF 457766) in which the sails are mounted on an iron cross instead of the conventional poll end. Six sails were more satisfactory and a six-sail mill could still operate in balance with only four if necessary. Sibsey Mill, Lincolnshire (114/TF 344510), is an example. Of the seven eight-sail mills built in England, only one still survives, the spectacular Heckington Mill in Lincolnshire (113/TF 145436), originally built in the early nineteenth century but fitted with its present cap and sails in 1892. Bought by Kesteven County Council in 1953 and subsequently restored, the mill is accessible to the public on enquiry at the adjacent mill house.

As we have seen, it was necessary to keep the mill's sails facing into the wind, and with the medieval post mill, the miller hauled the tail pole around and moored it in a suitable position. He had to keep a constant eye on the



3 A tower mill: detail of the cap of the five-sail Maud Foster Mill, Boston, Lincolnshire

wind direction and strength to ensure efficient operation and to avoid possible disaster if the mill was 'tail winded' in a storm. Although some of the Dutch tower mills also have complex tail pole arrangements for moving their caps, in England it became general practice to rotate the cap by continuous chain operating a worm driving on to wooden cogs projecting from the curb. A good example, and one that may easily be seen, is on Bembridge Mill, Isle of Wight, but numerous variations exist, frequently with cast-iron gears and a toothed iron curb cast in segments. Fully automatic luffing of the sails came in the eighteenth century after Edmund Lee's 1745 patent for the

'fantail' or 'fly'. This early example of a servo-mechanism is very simple in principle and heralded the large number of improvements which were to culminate in the highly efficient nineteenth-century tower mills of the eastern counties. The fantail was a small wooden vaned wind-wheel fitted to the back of the mill at right-angles to the sails and coupled through gears and shafts to a winding mechanism. As the wind veered or backed, the fantail rotated and turned the sails into the wind. With the high gearing ratios used there was great sensitivity to minor variations in wind direction, so typical in England, and the fantail became a characteristic feature in other European countries as well. Generally speaking the fantail drove on to the curb of a tower or smock mill to rotate the cap but a few post mills had them also and in these cases the drive was transmitted to wheels at the foot of the 'tail pole', which ran on a circular track. Post mills with fantails include Saxtead Green, Suffolk (137/TM 254644), maintained by the Department of the Environment and open to the public, Great Chishill Mill, Cambridgeshire (148/TL 413388), Holton Mill, Suffolk (137/TM 402776), and Cross-in-Hand Mill, Sussex (183/TQ 558218).

Transmission of power from the sails to the grinding stones was modelled initially on the medieval watermill and the design of gearing passed through similar stages of development in both types. Most early waterwheels, particularly in corn mills, had 'compass arms', that is spokes morticed into the wooden shaft, which was thereby not only weakened but made liable to rotting. An initial improvement was to provide 'clasp arms', whereby the spokes embraced rather than penetrated the shaft, and in the late eighteenth century cast-iron bevel wheels superseded the traditional combination of wooden face wheel and lantern pinion. Timber gears were never entirely displaced, however, and many can still be seen in both windmills and watermills. So too can morticed gears in which wooden teeth, usually of hornbeam or apple, are wedged into a cast-iron wheel which runs against the teeth of an all iron gear. This arrangement runs quietly with the minimum of wear.

In the windmill the general arrangement of the drive was from the great face wheel or 'brake-wheel' mounted on the windshaft to the 'wallower' on the top of the vertical main shaft running down the centre of the mill body or tower. A 'great spur wheel' on the main shaft drove a small 'stone nut' on top of the 'stone spindle', which in turn rotated the upper runner stone. Early mills had one pair of stones, but as post mills increased in size,

a second pair were usually included.

Grain was fed to the millstones by gravity. Corn was initially taken by sack hoist, which was usually powered by the sails, to the top of the mill where it was put in the grain bin. A chute took it to a hopper above the millstones and the grain trickled from the bottom of the hopper into a 'feed shoe' which was vibrated by the 'damsel', an extension of the stone spindle in the form of a cam. As the upper or runner stone revolved, grain was fed into the eye to be ground and expelled at the outer circumference of the stones. Only the upper stone revolved, and it did not come into contact with the stationary bedstone below. The space between the surfaces of the stones was carefully controlled to produce the best results. Nevertheless the meal falling away from the rim of the stones into the meal spout and finally into the bin on the floor below is surprisingly warm to the touch, an indication of the considerable power absorbed in the grinding process. Keeping the stones in correct relation to each other is known as 'tentering' and taxed the ingenuity of both millwright and miller to find a means of carrying out the operation automatically. The distance apart of the stones must relate to the speed of the mill, so a number of factors had to be related. As we have seen, the fantail and various automatic patent sails were in effect regulators or servo-mechanisms. Another type, which probably originated in mills, was the centrifugal ball governor in which two bob weights when rotated at speed moved outwards from the drive spindle. This movement could be coupled to brake the speed of the sails or, more commonly, to regulate the distance apart of the millstones. The use of these governors in windmills and watermills almost certainly predates their introduction and patenting by James Watt for regulating the supply of steam to steam engines.

Many mills operated two types of stone and both can frequently be seen today, in mills or standing decoratively in the open, often an indication that a windmill or watermill nearby has gone out of use or been demolished. Derbyshire Peak stones of grey millstone grit were used for barley, but flour was usually processed on the harder French burr stones which were more suitable for finer grinding. These latter stones were not cut from a single piece, as were the Derbyshire ones, but built up out of sections of quartz cemented together and bound with iron bands. The surfaces of the stones had a series of radial grooves in them which facilitated the grinding of the grain and encouraged the resultant meal outwards towards the rim.

The stones would be dressed from time to time by recutting the grooves using hardened steel mill bits wedged into a mason's maul. Not all stones revolved in the same direction, although millstones which revolved clockwise were easier to dress. This usually implied an anti-clockwise rotation of the sails in the normal post mill. It is always possible to work out which way the sails rotated on a derelict or disused mill by examining the sailstock or whip, which was always at the leading edge of the sails, or by observing the wear on the gear teeth.

Not all windmills were for grinding corn, their other major use being for drainage of low-lying areas such as the Fens. Wind power was used extensively from the sixteenth century onwards in the numerous Fenland drainage schemes and a number of windmills still survive, although no longer working. Naturally enough they derive some of their design features from Holland and many had a distinctly Dutch look, with squat towers, common sails and tail poles. Most early drainage mills were of the smock type but later examples were brick, often tarred. The machinery inside was much simpler than that in a corn mill. A conventional brake wheel on the windshaft drove the wallower on the vertical shaft, which at ground level had a bevel gear that drove in its turn a pit wheel on a horizontal shaft. On the other end of this shaft, usually on the outside of the windmill structure, was a scoop wheel which lifted water up and discharged it at a higher level. Sometimes, as at Horsey, a turbine pump was used.

Today few drainage mills survive intact, their decline beginning quite early in the nineteenth century when large capacity steam pumps were installed, each one capable of replacing a number of windmills. Fine examples of mills can still be seen, however, at Wicken Fen, Cambridgeshire (135/TL 562706), belonging to the National Trust; Horsey Mill (126/TG 457223) and Berney Arms Mill (126/TG 465051), both in Norfolk. This last mill, said to be the tallest in East Anglia, has a 70 ft tower and is preserved by the Department of the Environment. A curious feature is that the scoop wheel is separate from the mill itself and connected to it by a rotating drive shaft. It is also unusual in being used for grinding cement clinker and having access only by rail or water.

Although the traditional mill is now completely obsolete, a much more recent counterpart, which enjoyed considerable popularity down to the 1930s, can still be found fairly commonly. Wind pumps, used for raising

water for farm use, are automatic in operation. Most types have a steel wire-braced tower, with a multi-bladed wind vane and driving a reciprocating lift pump by means of a crankshaft geared down from the windshaft. Although relatively modern, operating examples are becoming surprisingly scarce, their role usually having been usurped by electric or internal combustion engine pumps.

There are still some 300 windmills in Britain of which reasonably complete remains survive and many more in the form of derelict towers or conversions into houses. Most are in the Eastern Counties, with notable concentrations in Essex, Kent, Lincolnshire, Norfolk, Suffolk and Sussex. Many of them are preserved. There were isolated pockets of wind power in the west, however, usually in areas where surface water was unavailable or not easily utilised. In England the Somerset levels, Wirral peninsula of Cheshire and Fylde of Lancashire all once had numerous windmills, although little evidence of them now survives. Ashton Mill, Chapel Allerton (165/ST 414504), is the best Somerset example; Bidston Mill (100/ST 287894) near Birkenhead still has sails but no internal machinery, while on the Fylde, Marsh Mill, Thornton Cleveleys (94/SD 335426), is being preserved by the local District Council. On Anglesey, the single area of Wales where windmills were common, only derelict towers survive.

#### WATER POWER

The first watermills in Britain were for grinding corn and this purpose remained by far the most widespread use of water power. Unlike the windmill, however, water was employed to drive a wide variety of industrial equipment, beginning with the water-powered textile fulling mill that was probably developed during the twelfth century. The earliest types of waterwheel used in Britain, of which examples still survive, were called Norse mills. They had vertical shafts and inclined wooden blades rather like scoops and developed at the most about  $\frac{1}{2}$ hp. One Norse mill preserved in Britain is Click Mill in Orkney (HY 290200), which is maintained by the Department of the Environment as an Ancient Monument. The wheel powers directly a single pair of millstones, the drive being taken through the eye of the bottom stone, which remains stationary, the top stone rotating above it.

It is known that the Romans used water power in Britain—three water-mill sites have been excavated along Hadrian's Wall, for example—but no detailed evidence survives. These Roman mills were probably very like the waterwheels used extensively in Britain from the eighth century onwards. Known generally as Vitruvian mills after Vitruvius, the engineer and architect who first described them, they had horizontal shafts with flat buckets that dipped into fast running water of a stream or river. Besides these primitive stream wheels the Romans also used overshot wheels at least as early as the fourth century AD and possibly earlier.

Little is known of the development of water power during the Dark Ages but by the *Domesday Survey*, begun in 1080 and completed in 1086, there were over 5,000 corn mills in England, most of them south and east of the Rivers Trent and Severn. These were probably of both Norse and Vitruvian types, but the latter eventually predominated. A watermill is shown in Fig 3.

By the sixteenth century water was by far the most important source of motive power throughout Europe, and Britain was no exception. Although primarily used for corn milling, water also drove fulling mills, and hammers and bellows necessary for the manufacture of wrought and cast iron, wire drawing equipment, drills for gun barrels and machinery used to hoist, crush and stamp metalliferous ores. The availability of water for driving wheels became an important factor in the location of industry, and in the manufacture of wool textiles, for instance, where manual spinning, carding and weaving were carried out as a cottage industry in East Anglia and the East Midlands, the new water-powered fulling mills set up on streams in the Cotswolds, Yorkshire, the Lake District and the West of England drew the other processes to them. Similarly the iron industry, although primarily located near raw materials such as iron ore and charcoal, took advantage where possible of streams to power hammers and bellows. In Kent, Sussex and Surrey where the industry was centred this was not always easy, as streams were inconsistent in flow. In summer men might have to work the wheels like treadmills to keep things going. In the Lake District and Shropshire, however, two other areas where blast furnaces in particular became established, the streams had a more consistent flow, and it is interesting to speculate on how influential this factor was in encouraging the industry to these areas.

## WATERMILL

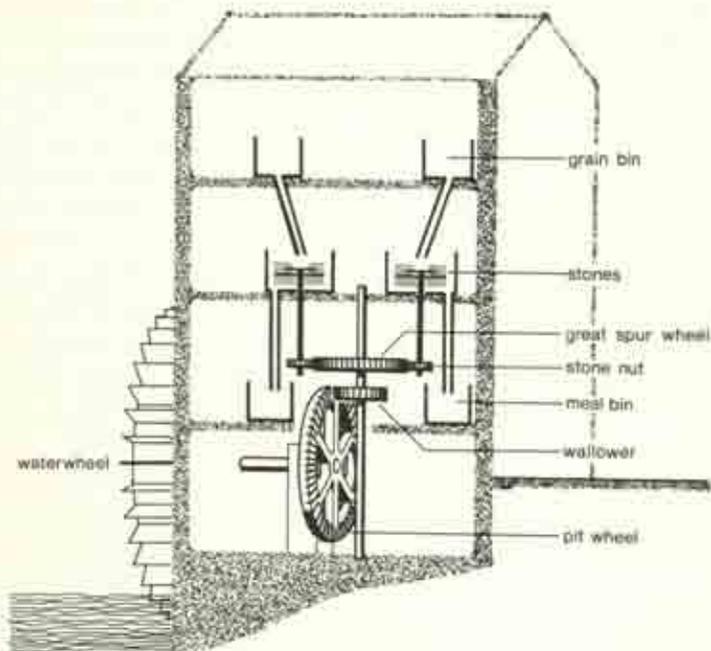
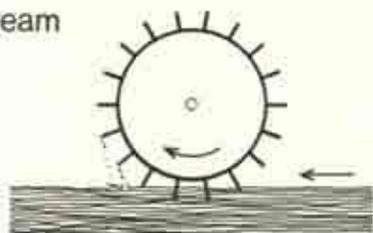
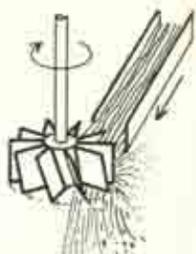


Fig 3

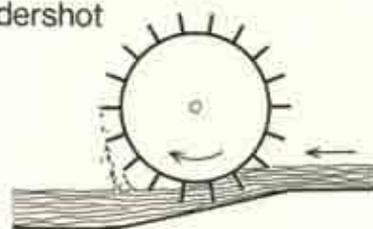
By the sixteenth century too a corpus of knowledge on waterwheel technology was being established. John Fitzherbert's *Boke of Surveyinge and Improvements*, published posthumously in 1539, notes that it was common to build corn mills not on large rivers but on a more convenient site served by a man-made millstream to a weir. Fitzherbert also refers to the need for an adequate fall in tailrace to minimise the disadvantages of back-watering, which in time of flood might cause the wheel to slow down through water building up below it. He also confirms that breastshot and overshot wheels produced more power than undershot wheels if their buckets were well filled, and that water should, as far as possible, be prevented from leaving the buckets before they reached their lowest point by the building of a close fitting breast of brick or stone shaped to the profile of about a quarter of the wheel and only an inch or so from it. Types of waterwheel are shown in Fig 4.

## TYPES OF WATERWHEEL

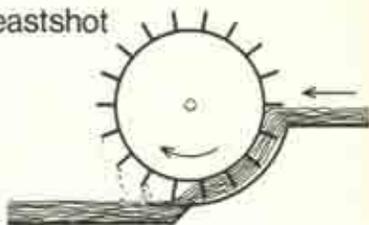
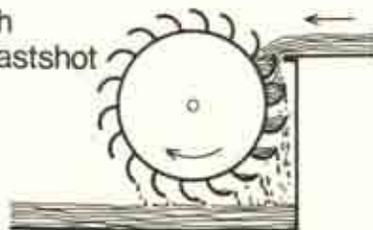
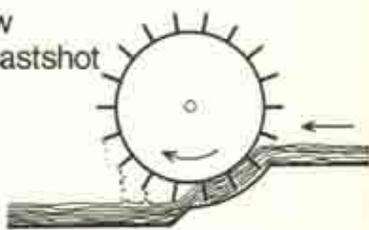
Stream

Horizontal  
or  
Norse mill

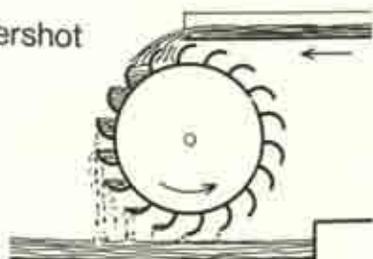
Undershot



Breastshot

High  
breastshotLow  
breastshot

Overshot



Pitchback

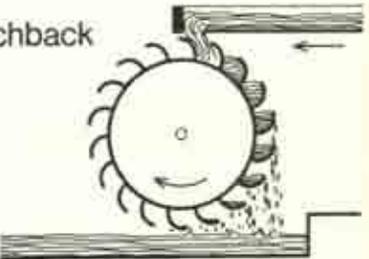


Fig 4

As industrialisation got under way in the early years of the eighteenth century, the simple undershot wheel was then the most numerous in Britain. It was cheap and easy to install, needed a minimum of groundworks to arrange its water supply and did the job for which it was required effectively if not efficiently. Mechanical inefficiency was of little importance if there was adequate water in the stream all the year round to drive a low hp wheel reliably. Only when greater power was demanded from limited supplies of water did other types of waterwheel become necessary. Thus in the eighteenth century eminent engineers such as John Rennie (1761-1821) and Sir Marc Isambard Brunel (1769-1849) used large undershot wheels to drive saw mills at Dartford and Chatham. One important modification in the design of the undershot wheel was made in the early years of the nineteenth century by J. V. Poncelet (1788-1867), and became widely adopted where maximum efficiency was required from a small head of water. By curving the paddles or blades of the wheel, as shown in Fig 4, he provided for the entry of water into the compartments without shock, the idea being that water would run up the surface of the vanes, come to rest at the inner diameter and then fall away from the wheel with practically no velocity. This design raised the efficiency of the undershot wheel from about 22 per cent to about 65 per cent.

Between 1750 and 1850 the waterwheel came into its own for industrial purposes, well after the steam engine had become firmly established. Water had been the primary source of power in the early years of the Industrial Revolution and the steam engine was at first as much a product of industrial growth as a contributor to its development. Waterwheels were cheap and easy to install and could drive machinery which the early non-rotative steam engines could not. Indeed the steam engine was used in the middle of the eighteenth century to pump back the tail water of the waterwheel and even to supply water to wheels which had no stream supply of their own. For example, Bedlam furnaces, built on the bank of the Severn at Ironbridge in 1757, relied on a Newcomen type steam engine to lift water from the river to drive an overshot and undershot wheel on each of the two sets of bellows. It is significant too that almost all the really high hp waterwheel installations, developing more than about 100 hp, were built between 1820 and 1850, long after the rotative steam engine had become well established.



4 Rossett Mill, Denbighshire. A seventeenth-century watermill with a nineteenth-century wheel

A major contribution to the improvement of waterwheel design resulted from the experiments of John Smeaton (1724–92), who built and tested models to determine the most efficient type of wheel. He established the principle that there must be considerable losses when a jet of water strikes the flat blade of an undershot wheel, and that it was clearly much better to develop power by filling the buckets of an overshot or breast wheel with water and doing the work by gravity rather than by impulse. Smeaton also introduced the first cast-iron shaft in 1769, which was fitted to the waterwheel of a furnace blowing engine at the Carron Ironworks in Scotland. This in itself was an important step forward as one of the major problems with developing a large output waterwheel was designing a shaft capable of transmitting the power. Smeaton's iron shafts were strong, and although they did not solve all the difficulties—they were subject to fracture in the region of the flanges—they provided some sort of answer to the problem until better designs were evolved. Plates 4 and 5, Rossett Mill, show a cast-iron shaft with wooden arms.



5 Rossett Mill. Detail of wheel showing cast-iron shaft and wooden arms

Metal construction throughout followed in the early years of the nineteenth century with cast iron replacing wood. Buckets were made of curved sheet iron, with the inlet angle carefully designed to reduce the shock loss of water entering the wheel and the bucket shaped to retain as much water as possible during the descent. As the size of waterwheels increased, both in diameter and width, trouble was experienced with air locks as the water entered the buckets and also, when water in the tailrace was high and the bottom of the wheel submerged, with water leaving. The remedy was found by Sir William Fairbairn (1789–1874) who described it thus:

It was observed that when the wheel was loaded in flood waters, each of the buckets acted as a water blast, and forced the water and spray to a height of 6 or 8 feet above the orifice at which it entered . . . in order to remedy it openings were cut in the sole plates, and small interior buckets attached, inside the sole . . . The air in the bucket made its escape through the opening and passed upwards . . . permitting the free reception of the water . . . The buckets were thus effectively cleared of air as they were filling . . .

Fairbairn claimed an increase of power resulting from this modification of some 25 per cent.

From the end of the eighteenth century the use of high hp waterwheels for driving factories posed new transmission design problems. Wheels developing as much as 100 hp were becoming common, and contemporary wheel shafts, even those made of iron, could not transmit this power at the low speeds then employed. The difficulty was overcome by taking the power from the wheel at its periphery where a segmental gear wheel, usually of cast-iron sections attached to the rim or spokes of the waterwheel, drove a smaller pinion wheel. Thus the secondary shaft rotated at a much higher speed and the wheel shaft had only to be strong enough to support the weight of the waterwheel itself. Spokes too could be of lighter section as they no longer transmitted power, the ultimate result of this trend being the suspension wheel in which the spokes, like the spokes of a bicycle wheel, were of thin section and in tension rather than compression. Generally speaking the position of the power take-off on waterwheels with a rim drive was as close as possible to where the power was being generated—immediately below the sluice through which water entered the wheel.

The suspension wheel was developed by Thomas Cheek Hewes (1768–1832), an engineer and textile machine manufacturer of Manchester, in association with William Strutt (1756–1830) of Derby. Hewes was an early pioneer in the application of cast and wrought iron and for a short but crucial period in 1816–17 employed William Fairbairn (later Sir William), who later achieved much greater renown. Thwaite Mill, Hunslet, Leeds (96/SE 318312), rebuilt in 1823 by Hewes and Wren, still uses water power in the manufacture of putty. Perhaps the finest suspension wheel still in existence was made by the same firm in 1826 for Woodside Mills, Aberdeen, and is now preserved in the Royal Scottish Museum, Edinburgh. The wheel is 25ft in diameter and 21ft wide. It generated over 200 hp with an 18ft head of water, transmitting power by a rim gear of twelve cast-iron segments. There are forty-eight wooden ventilated buckets, twelve wrought-iron spokes of 2½in diameter on each side of the wheel and a similar number of diagonal wrought-iron braces. The shaft, of cast iron with a cruciform section, is of a type known as a feathered shaft. Similar ones can be seen at Thwaite Mill, Leeds, and Stryal Mill, Cheshire (101/SJ 834830), although the latter no longer has the wheel itself. Another large suspension wheel is at

Hartlington Mill, Burnshall, Wharfedale (90/SE 042609). Unfortunately these most sophisticated of waterwheels, nearly all of which were installed to drive factories, have largely disappeared as the result of the competition from steam engines during the latter part of the nineteenth century. Thus, while many hundreds of relatively primitive wheels in rural corn mills survive, very few high hp industrial waterwheels still remain *in situ*.

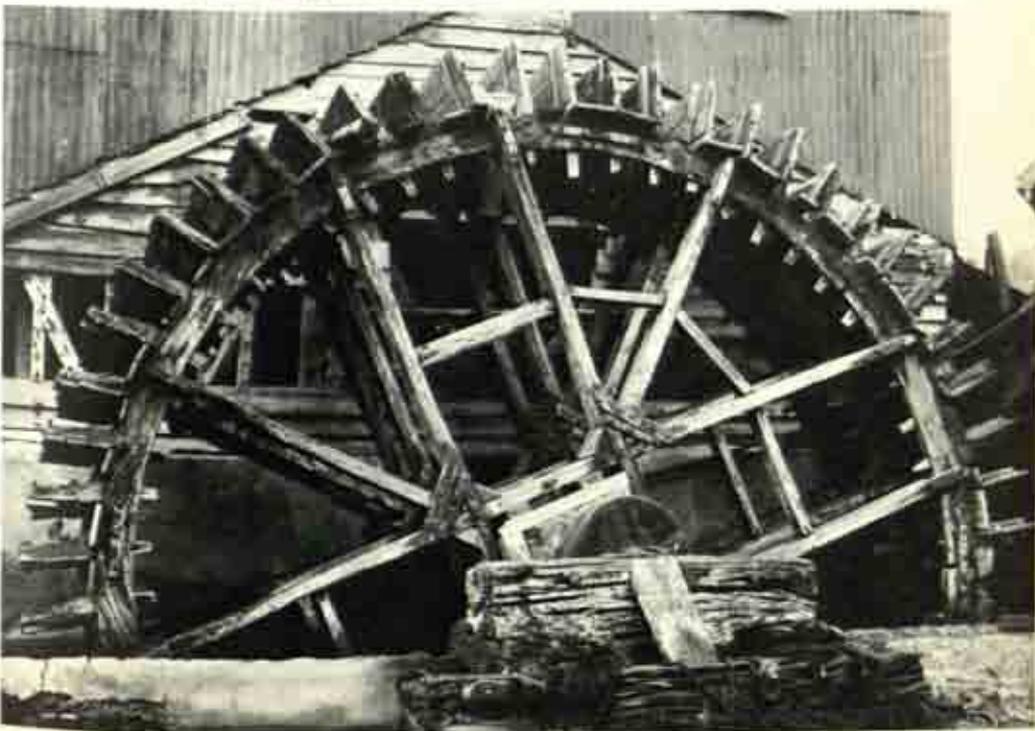
Not all large wheels were of the pure suspension type although a number had lightweight spokes. An example is the 33 ft diameter overshot wheel at Killhope lead mill in Weardale, County Durham (84/NY 827429). Here the spokes are of flat section wrought iron and rigidity is maintained by cross bracing. The wheel once drove lead crushers which, like the wooden launder that supplied its water, have now gone. The site is preserved as part of a Durham County Council picnic area. Another large diameter wheel is at Lothersdale Mill, Keighley, Yorkshire (95/SD 959459). Built in 1861 it is 44ft in diameter, 5ft rim wide and has an unusual arrangement of alternating wooden spokes and wrought-iron tension rods. It is a high breast wheel with U-shaped floats of sheet iron and there is an outside rim drive. It powered cotton spinning and weaving machinery until the 1930s. At Foster Beck Mill, Pateley Bridge, Yorkshire (91/SD 148664), is a fine external breast wheel 35ft in diameter. It has wooden spokes and rim drive but no bracing, and the 'penstock' from which the water was fed to the wheel through a sliding hatch or 'shuttle' is particularly conspicuous. The wheel drove a hemp mill which has now closed and the machinery has been removed.

The largest waterwheel ever built in Britain is the celebrated *Lady Isabella* installed in 1854 by the Great Laxey Mining Company of the Isle of Man (87/SC 432852). It is 72ft in diameter and 6ft rim wide and was built to pump water from a lead and zinc mine 1,480ft deep. The drive was by means of a crank on the shaft and 600ft of timber connecting rods. The wheel, which has wooden spokes and wrought-iron diagonal bracing rods, is of the pitchback type (see Fig 4) in which the water is reversed in direction at the point of access, in contrast to the conventional overshot wheel where the direction of flow is continuous. This somewhat unusual feature was probably adopted as a means of securing efficient entry of water into the buckets and to avoid the constructional problems of carrying the high-level leat beyond the wheel centre as in a normal overshot wheel. Another

possible advantage was that the water leaving the wheel flowed away down the tailrace in the same direction as the wheel was rotating. The *Lady Isabella* last worked the mine pumps in 1926, was restored in the late 1920s, and in 1965 was bought by the Manx Government whose Tourist Board now maintains it. During recent renovations the spokes have been replaced by steel girders, clad in timber to retain the original appearance.

In coastal areas tide mills took advantage of the fact that water could be ponded up in a small estuary or creek at high tide and used to drive a waterwheel—usually of the low breast or undershot type—over the period of low tide. There were two working shifts in each 24 hr period and, because of the successional movement of the tides, the tide miller worked somewhat unusual hours. The last operating tide mill (Plate 6) in Britain, on the River Deben at Woodbridge in Suffolk (150/TM 276847), is the subject of a preservation scheme. The mill ran until 1956 when the 22in square oak shaft of the waterwheel broke, but since then a trust has been established to raise the money necessary to restore the machinery and timber-framed building. A much less common use of water power was to drive beam pumps used in mine drainage and one incomplete example survives at

6 Woodbridge tide mill, Suffolk. The waterwheel before restoration



Straitsteps lead mine, Wanlockhead, Dumfriesshire (68/NS 855144). At one end of the beam is a broken pump rod which once went down the mine shaft. At the other end a bucket rod is connected to the beam via a cross-head moving in guides and a connecting rod. The method of operation was for the the bucket to be filled from a nearby stream supply until the weight of water caused the beam to fall, raising the other end and the column of water in the pump barrel in the shaft. When the full bucket reached the end of its travel, a valve in the bottom was triggered open, the water flowed out, and the pump end of the beam, appropriately weighted, fell, filling the pump barrel again. The Wanlockhead water-bucket engine, which is thought to date from the 1880s, is being preserved by the Leadhills and Wanlockhead Mines Research Group. It is scheduled as an Ancient Monument. A recently restored waterwheel-powered beam pump is situated at Wheal Martyn in Cornwall (185/SX 004555).

The use of water for power provides a fruitful and worthwhile area of study for the industrial archaeologist, as surviving evidence in the form of wheels and the watercourses associated with them is plentiful. There are thousands of sites, in England particularly, where a small weir, a rotting sluice-gate or a dried-up leat provide the clue to a once thriving water-powered mill or factory. Investigation of these remains is in many cases truly archaeological in nature, as although documentary or map evidence is often available to locate a watermill site, most details of its technology—what type of wheel and transmission gear was used, for example—can only be discovered by fieldwork.

A number of basic principles can be applied to help with these on-site investigations. The basic requirements of a waterwheel were a head of water to drive it, a consistent and controllable flow of water and avoidance, if possible, of the effects of mild flooding. On a large slow-flowing stream or river with a relatively low gradient the easiest and cheapest mill to build would have a short leat taking water to the wheel which, because only a low head would be available, would have to be of the undershot type. The mill might be susceptible to flooding and a more reliable siting might involve a longer leat and tailrace (to avoid water backing up on the wheel) and perhaps a low weir in the river. By using a long leat a greater head of water would be made available, and a breastshot or overshot wheel might be installed to provide greater power for a given size of wheel. If the stream or

river was particularly susceptible to minor changes in level, a long weir placed diagonally across the stream could minimise these effects, combining the merits of a long leat in creating a good head of water and an efficient governor for the wheel. The longer the weir, the less variation is there in water level during spates.

If the stream supply was small or the flow inconsistent, water would have to be collected in a millpond and, in certain cases, a type of wheel that would derive maximum power from a limited supply would have to be devised. There are two ways of gaining more power from a waterwheel—increasing its width or increasing its diameter. A good example of a wide wheel is to be found at Claverton (166/ST 791644) on the River Avon near Bath, where a waterwheel provided power for a beam pump designed to lift water from the river into the Kennet & Avon Canal. Here the head is low but the supply plentiful, so to obtain the necessary power, this low breastshot wheel was built some 24ft wide. The present installation contains an interesting design modification, as the shaft of the original c 1810 wheel was not stiff enough, and a cast-iron A frame and bearing had to be fitted to provide intermediate support to the shaft, which now carries two wheels in parallel, each one 11ft 6in wide.

In situations where the volume of water was low and water storage impracticable or too expensive the only way to obtain high power outputs was by building large-diameter wheels. In some cases the supply of the waterwheel would be by a pipe, as at Pateley Bridge (91/SD 148664) and the *Lady Isabella*; with the latter the pipe approaches at ground level and rises vertically inside a stone tower to feed the top of the wheel. Another large diameter wheel where water supply has always been a problem is at Priston Mill in Somerset (166/ST 695615) where an iron overshot wheel is fed from a pond.

The factors which led to the decline of water power are more complex than might at first be imagined. The popular notion that the steam engine was immediately responsible for the elimination of the waterwheel is far from true, and many large and successful waterwheels were being installed throughout the first half of the nineteenth century. Indeed it was not until the 1840s that steam engines were being built to exceed the hp of the largest waterwheels. As late as 1834 estimates by the first four factory inspectors indicate that approximately one-third of the power used in cotton mills in Britain was from water. A further factor in the decline of water power

during the latter part of the nineteenth century was the steadily increasing diversion of water from higher districts to supply the domestic needs of the new towns, while Fairbairn, writing in 1864, claimed that land drainage schemes had altered river regimes drastically, resulting in rapid run-off, a higher incidence of flooding and subsequent low water conditions, all of which were detrimental to water power users.

By the latter part of the nineteenth century, however, steam engines began to replace waterwheels, particularly in large-scale industrial locations where technology was evolving rapidly and power requirements were increasing. The rurally based industry on the other hand often continued to use the waterwheel as its main source of power, perhaps adding a small steam engine or later an oil engine as a supplementary source. There was little incentive to change from water if it did the job. Maintenance costs were low and nothing went on fuel. The major factor in bringing about the closure of the large majority of watermills (those grinding corn) was not directly related to the power source. During the latter years of the nineteenth century the increasing importation of foreign grains and the introduction of roller mills led to very large flour milling complexes being set up at the major ports. The small miller, whether he was using wind or water power, could rarely compete and almost all flour production soon passed into the hands of big companies. Today a few small corn mills are still working, mainly for the production of animal feed.

Nevertheless a surprising number of waterwheels can still be seen in operation, in most cases preserved, but indicating the very wide variety of applications in which water power has been used in very recent years. At Sticklepath in Devon (175/SX 643940) is Finch Foundry, a water-powered scythe and edge tool works with hammers and grinding wheels. Abbeydale (111/SK 325820) and Shepherd Wheel (111/SK 317854) in Sheffield also have preserved and operational waterwheels driving basically the same types of equipment, while in Cornwall the Tolgus Tin Company (189/SW 690438) uses water to drive ore-crushing stamps. At Redditch, Worcestershire (131/SP 046686), a needle mill is water-driven; and at Cheddleton in North Staffordshire (110/SJ 973526) flint grinding mills are water-powered. Working preserved corn mills include High Mill, Skipton (95/SD 989518), Nether Alderley, Cheshire (101/SJ 844763), and Preston Mill, East Linton, East Lothian (63/NT 595779).

## 4 Steam and Internal Combustion Engines

It is perhaps not generally realised that a high proportion of the total requirements of energy in Britain today is satisfied by steam power in the form of steam turbines, which are amongst the largest and most efficient prime movers employing heat energy, and generate most of the electricity we use. At one time the reciprocating steam engine, that is one employing a piston moving backwards and forwards in a cylinder, held this pre-eminent position, but although it has not been entirely displaced, still finding specialist applications in a number of fields, its use has declined considerably. Steam turbines, diesel engines and gas turbines have superseded it after over 250 years, during which period the steam engine was unchallenged for almost two centuries. In those 200 years Britain and many other countries were transformed into highly industrialised, technology-based societies; the significance of the steam engine in bringing about this transformation is inestimable. As a means of draining mines, of powering textile machinery, of driving railway locomotives and ships, and now of generating electricity, the power of steam, harnessed successfully in the early years of the eighteenth century, is without doubt the greatest single technological factor in the huge social and economic changes which we have called the Industrial Revolution. The significance of the steam engine far transcends its purely technical aspects; its evolution was the first major step in the liberation of mankind from toil and the development of our complex society.

### THE STEAM ENGINE

In the late seventeenth century mines had become sufficiently deep to create serious problems of drainage, a difficulty overcome in some instances by the use of water-powered pumps but more often by men and horses. Severe limitations were imposed on further deep mining by the capacity and expense of mine-pumping equipment. It was into this field of outstanding need that the steam engine came as a result of the discovery that the pressure of the atmosphere could be applied to do useful work.

Before examining the evolution of the steam engine proper it will be worthwhile to consider the state of experimental science at the end of the seventeenth century and the extent of the knowledge about the atmosphere and the properties of gases at that time. As early as the first century AD Hero of Alexandria had demonstrated that gases expanded and contracted when heated and cooled respectively, but it was not until 1606 that an experiment, carried out by Giovanni Battista della Porta of Naples, used the pressure of steam generated in a flask to force the water out of an enclosed tank. He also described how a flask full of steam and with its neck in a vessel of water would draw up water as the steam condensed, the principle being that 'nature abhorred a vacuum'. The fundamental breakthrough, the realisation that the atmosphere has weight, was made in 1643 by Evangelista Torricelli (1608-47), a pupil of Galileo, when attempting to explain why a suction pump would not draw water from a depth greater than about 28 ft. After experiments with mercury he stated that the atmosphere exerted a pressure because of its weight and that this would support a column of water 28 ft high or, in the case of the much denser mercury, some 30 in in height. It was this discovery that established one of the basic principles on which the first generation of steam engines depended and also, of course, resulted in the invention of the mercurial barometer.

The power of atmospheric pressure was further demonstrated in the 1650s by Otto von Guericke (1602-66), of Magdeburg, who succeeded in evacuating a copper sphere, which resulted in its collapse. Later he evacuated the air from a cylinder having an accurately fitting piston and utilised the atmospheric pressure to raise a weight of over a ton. It was the Dutch scientist Christiaan Huygens (1629-95), and his assistant Denis Papin (1647-1712?), however, who in 1690 used the condensation of steam beneath a piston in a cylinder as a means of creating the vacuum, a great improvement on the air pump used by von Guericke. Although Papin never developed his ideas to a larger scale than an experimental model with a 2½ in diameter cylinder, he had in his grasp all the fundamentals that were to be applied in practical terms by Thomas Newcomen 20 years later.

The first practical application of steam power and a steam-generated vacuum for mine drainage was, however, not evolved from Papin's work with pistons in cylinders but derived its principles from della Porta's steam pressure and vacuum experiments of 1606. In 1698 Thomas Savery (c 1650-

1717), a Cornish engineer, patented a machine for the 'Raising of Water . . . by the Impellant Force of Fire'. Steam from a boiler was admitted into a closed vessel and condensed by pouring water on its outside. The resultant vacuum caused water to rise up a suction pipe through a non-return valve into the bottom of the vessel. Steam was then admitted again and the pressure drove the water in the vessel through a second non-return valve and up the delivery pipe. The major difficulties encountered with the Savery engine, the so-called 'Miners' Friend' which probably never actually operated in service at a mine, was that boilers capable of withstanding pressures of several atmospheres could not be easily made at that time and that the length of the suction pipe was limited to about 25ft, making the engine unsuitable for deep drainage work. Certainly Savery's engine never entered widespread use and there are no surviving remains. Savery's work was not completely a dead end, however, as in the late-nineteenth century the portable Pulsometer steam pump was developed on very similar principles. The main working part was an oscillating valve admitting steam alternately to two water chambers. The steam pressure acted directly on the surface of the water in the chamber and ejected it through a flexible hose. Pulsometer pumps can still be seen occasionally, their main use being for draining excavations and flooded mines, and ship salvage. Lightweight internal-combustion engine pumps are supplanting them.

To return to the early development of the steam engine, it was in Papin's piston and cylinder experiments that the germ of the commercially successful machine lay. Papin did not pursue his experiments but Thomas Newcomen (1663-1729), an ironmonger of Dartmouth working on similar principles but almost certainly without knowledge of the Dutch scientist's work, was actively pushing towards a practical application. Newcomen was well aware of the critical drainage problems in the Cornish tin mines, and after pursuing experiments for some 15 years in an attempt to find a solution, he erected his first engine in 1712 (Fig 5). Curiously this was not in Cornwall but at a colliery near Dudley Castle, Worcestershire. It had a cylinder of 19in diameter, a stroke of 6ft and developed some  $5\frac{1}{2}$  hp.

The principle of operation was both simple and extremely reliable and, at least as important, no advanced technology was involved in the engine's manufacture or erection. An open-topped vertical cylinder contained a piston connected through a piston rod and chain to the arch head of a

## NEWCOMEN'S ATMOSPHERIC ENGINE, 1712

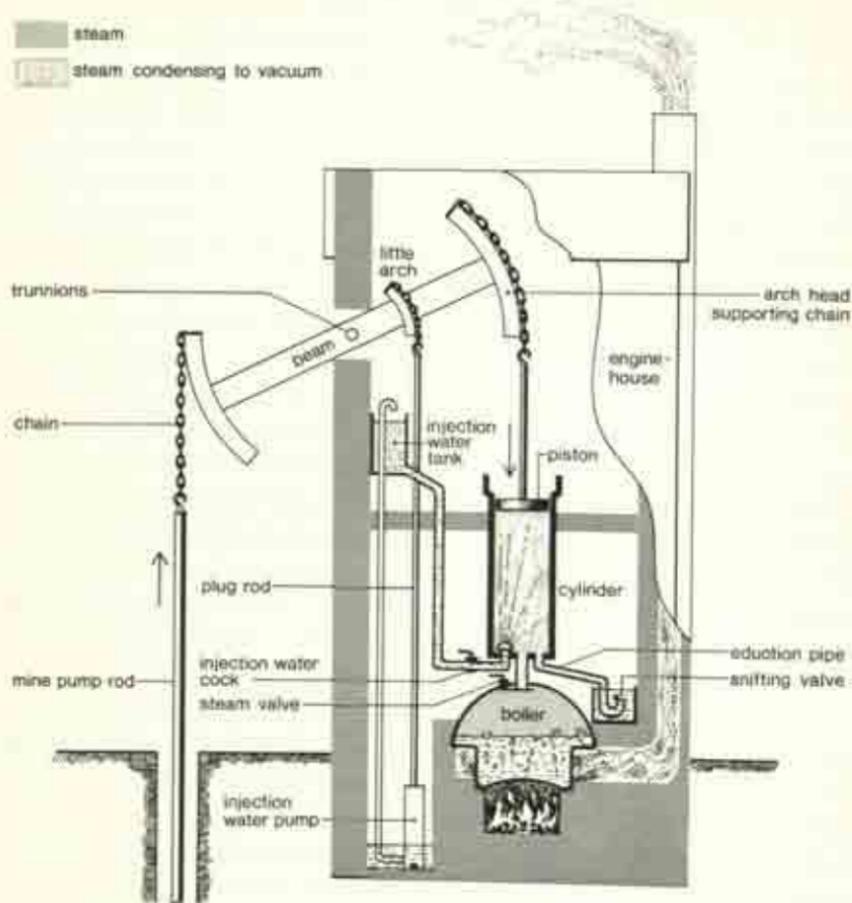


Fig 5

rocking beam. The 'piston ring' consisted of a disc of leather cupped upwards and kept pressed against the bore of the cylinder by a layer of water on top. From the end of the beam distant from the steam cylinder the pump rods were suspended. Below the cylinder was mounted a boiler which was little more than a tank of water with a fire beneath it and rather like a brewer's copper in appearance. When steam at slightly above atmospheric pressure was admitted into the cylinder, the piston was drawn upwards by

the weight of the pump rods on the other end of the beam. At the same time any air in the cylinder was ejected through non-return valves. Closure of the steam inlet valve was followed by condensation of the steam in the cylinder by a jet of cold water which created a partial vacuum and allowed the unbalanced atmospheric pressure on the top of the piston to push it down, raise the pump rods and thus make a working stroke. The cycle was then repeated, the steam valve and injection cock being opened and closed by a plug rod also hung from the beam.

Newcomen's initial design was thoroughly practical and was little altered for more than half a century. At first royalty payments had to be made to Savery, whose original patent covered all methods of raising water by fire, but after 1715, when Savery died, a group of speculators, including Newcomen himself until his death in 1729, acquired the rights and administered them until they expired in 1733. By the time of Newcomen's death his engine was in use throughout Britain and in Hungary, France, Belgium and possibly Germany and Spain. It is doubtful if Newcomen gained much, if any, financial benefit from his invention, which with the possible exception of Abraham Darby's perfection of coke smelting of iron ore, perhaps constituted the most important single technological factor in bringing man into the modern world.

One of the most important surviving memorials to Thomas Newcomen is the Hawkesbury engine, re-erected in the Royal Avenue Gardens, Dartmouth (188/SX 879515), and opened to the public in July 1964 to commemorate the 300th anniversary of its inventor's birth. The engine probably dates from the mid-1720s and is the oldest steam engine in existence. It was originally installed at Griff Colliery, Warwickshire, later moved to Measham, and in 1821 was installed on the bank of the Coventry Canal at Hawkesbury Junction (132/SP 363846), where it was used to raise water from a sump into the canal itself. The engine was occasionally worked until 1913 and in 1963 was presented to the Newcomen Society by its owners, the then British Transport Commission. Incidentally the canal-side site at Hawkesbury is in itself still well worth a visit as a relatively unspoilt junction with cast-iron bridges and boatmen's pub.

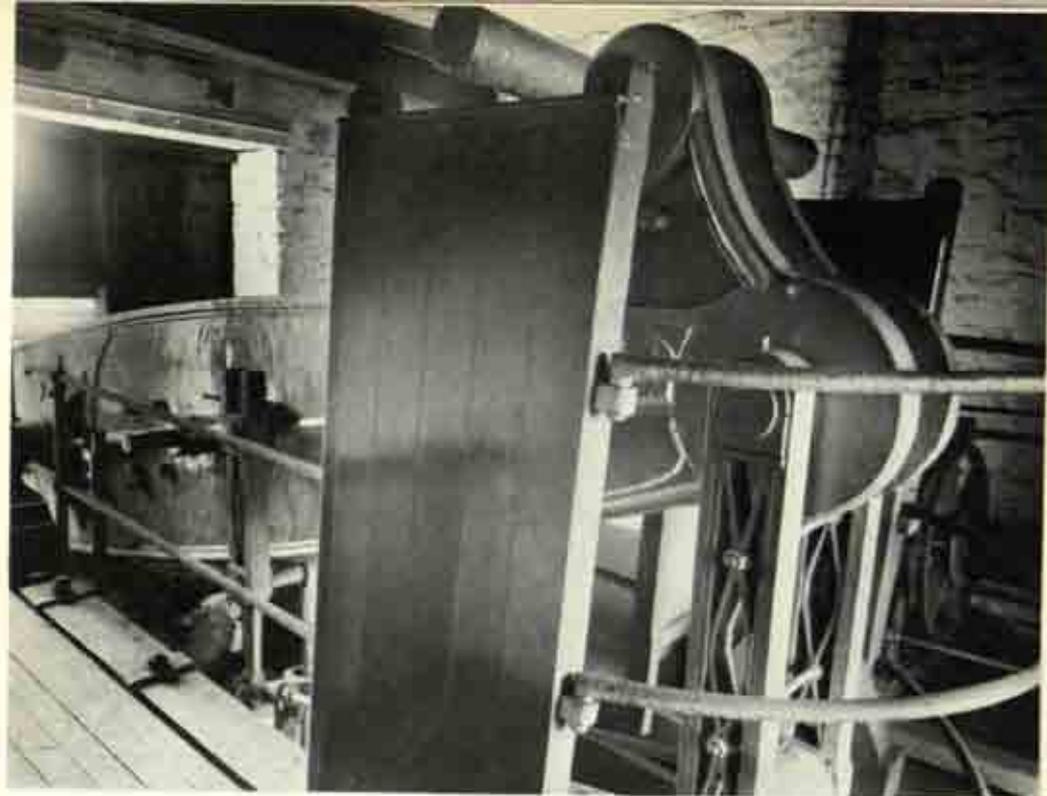
A number of modifications may be seen on the Hawkesbury engine, the most significant of which is the 'pickle-pot' condenser below the cylinder, an improvement in design to increase thermal efficiency and at the same

time avoid an infringement of Watt's separate condenser patent, discussed below. Another surviving engine of Newcomen type stands at Elsecar (102/SE 390003) in the West Riding of Yorkshire, where it was used for colliery drainage from 1787 until 1923. Again numerous modifications have been made from the original, including replacement of the wooden beam by a cast-iron one. Condensation of the steam, however, was effected within the working cylinder by the use of a jet of cold water in almost exactly the same manner which Newcomen had applied in his first 1712 engine. The Elsecar engine (Plates 7-10) is now preserved on its original site by the National Coal Board and may be visited by arrangement with the South Yorkshire Area office at Wath-upon-Deerne, Rotherham.

Before leaving the Newcomen type of atmospheric engine it is worthwhile considering some of its constructional details and the improvements which were made in its efficiency. The atmospheric engine was a thoroughly practical machine and the techniques necessary for its manufacture were all well known to the millwrights and similar men who were responsible for its erection. Only the cylinders caused any serious problem. Initially these were cast in brass and, as no means of accurately machining the bore existed, they were rubbed smooth on the inside with abrasives. Small wonder,

7 Atmospheric beam pumping engine, Elsecar, near Rotherham, Yorkshire, preserved by the National Coal Board





8 Elsecar beam engine. Detail of beam and parallel motion

therefore, that the cylinder was the most expensive single component of the engine, exceeding even the engine-house in cost. A 1733 estimate for a Newcomen-type engine near Newcastle-upon-Tyne totalled £849, of which £150 was accounted for by the cylinder alone. By the 1740s cast-iron cylinders were becoming common and, although less efficient thermally because of their greater wall thickness, they were significantly cheaper in first cost.

John Smeaton (1724-92) was responsible for bringing about the greatest improvements in efficiency of the Newcomen engine, and a machine which he erected at Long Benton Colliery, Northumberland, in 1772 achieved a duty of 9.45 million foot-pounds of useful work per bushel (84 lb) of coal. The average Newcomen engine only achieved 6 million foot-pounds. Despite his improvements, which were largely the result of careful design and manufacture, particularly of the cylinder, Smeaton's engine had a



9 Elsecar beam engine. Detail of cast-iron beam

thermal efficiency of less than 1 per cent.

It was James Watt (1736–1819) who solved the problem of the fundamental inefficiency of Newcomen's steam engine. Watt, a first-class craftsman, was employed as an instrument maker in Glasgow University where in the winter of 1763–4 he was responsible for the repair of a model Newcomen engine which was faulty in operation. His investigations led to the realisation that enormous thermal losses resulted from having to raise and lower the temperature of the cylinder at each stroke, as steam was admitted

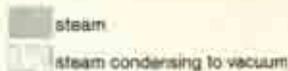


10 Elsecar beam engine. Open top of steam cylinder showing piston

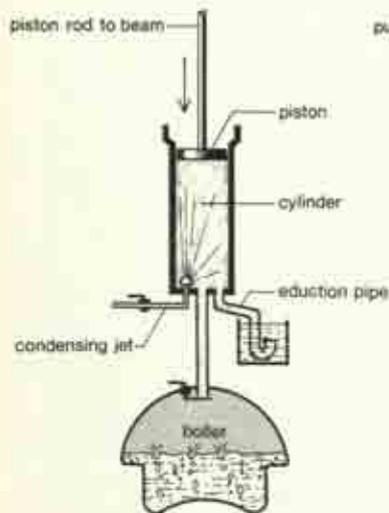
and subsequently condensed. As he wrote later: 'I perceived that, in order to make the best use of steam, it was necessary—first, that the cylinder should be maintained always as hot as the steam which entered it; and, secondly, that when the steam was condensed, the water of which it was composed, and the injection itself, should be cooled down to 100° (F), or lower, where that was possible.' His solution was to connect a closed vessel, exhausted of air, to the steam cylinder by a pipe. Steam rushed into this vessel, which was kept cool by cold water injection, and continued to do so until all had condensed. This was the basis of Watt's separate condenser (Fig 6), perhaps the greatest single improvement ever made in the efficiency of the steam engine. In order to keep the condenser free of air and the water resulting from injection and condensation, he used a pump connected

## NEWCOMEN & WATT ENGINES

Showing method of condensing steam



### NEWCOMEN condenses in cylinder



### WATT has separate condenser

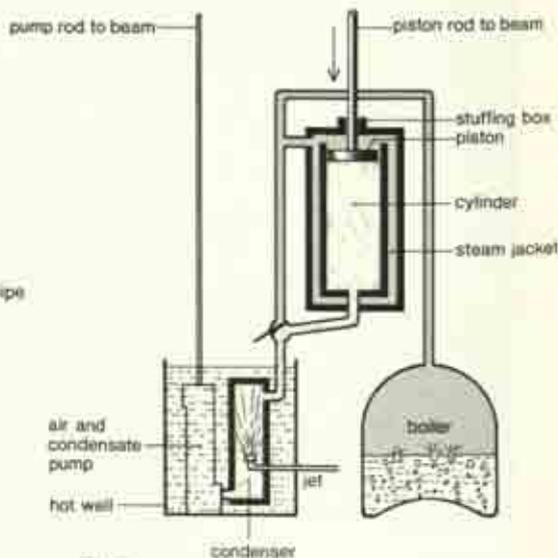


Fig 6

to the beam, while the working cylinder was kept permanently hot by means of a steam jacket. To improve efficiency still further, steam instead of atmospheric air was used to press the piston down, the piston rod passing through a steam-tight gland or stuffing box in the cover of the cylinder.

Watt patented his separate condenser in 1769 and in 1773 entered into partnership with the Birmingham entrepreneur and industrialist Matthew Boulton (1728-1809), whose works he had once visited when on a journey to London. There were only 8 years to run on the condenser patent but Watt successfully petitioned Parliament for an extension to 1800 and in 1776 completed his first two full-size engines, one for colliery drainage at Tipton, Staffordshire, and the other for blast furnace blowing at John Wilkinson's ironworks near Broseley in Shropshire. At his Broseley works

2 years earlier Wilkinson (1728-1808) had developed and patented a boring mill, initially for guns and then for steam engine cylinders. The significance of the boring mill in the success of the Watt engine cannot be overestimated as, for the first time, a large diameter bore could be cut so accurately that 'a 72 inch cylinder would not be further from absolute truth than the thickness of a thin sixpence in the worst part'. A model of a water-powered multiple-spindle cylinder boring mill can be seen in the Science Museum, South Kensington. There too are some of the most important relics of Watt's early career, including the cylinder and condenser which he probably used in his original experiments and the contents of his garret workshop from Heathfield, Birmingham. The workshop, containing some 6,000 separate items, was left undisturbed from 1819, when Watt died, until its removal in 1924 to the museum, where it has been set up in a replica room. The model Newcomen engine on which Watt carried out his earliest work on steam power is preserved in the Hunterian Museum at Glasgow University.

The first Boulton & Watt engines were an immediate success, consuming less than one-third of the coal used by the Newcomen types commonly in use, and as a result bringing enquiries from all over the country. The demand was greatest in Cornwall, where coal was expensive, so that within a few years all the atmospheric engines there had been replaced. The basis for installation of a Boulton & Watt engine was to charge a royalty equal to one-third of the saving in the cost of fuel as compared with that of a 'common' or atmospheric engine. Two engines at Poldice Mine, Cornwall, were tested and used as the standard. To register the number of strokes of the engine, from which the premium payments were calculated, a pendulum-operated counter in a locked box was attached to the beam.

Further improvements were devised by Watt, with the active encouragement of Matthew Boulton, who fully appreciated the potential market for efficient and reliable steam engines. In 1782, three important advances in design were patented by Watt. The first was to make the engine double-acting, that is to apply steam alternately on each face of the piston instead of only to the top as had been the previous practice. Thus twice the power could be developed from the same cylinder volume. The second used the steam expansively and, when perfected, resulted in considerable savings of fuel. The principle was that by closing the inlet valve to the cylinder when the piston had completed only a part of its stroke the steam already in the

cylinder would still do useful work by expanding and pushing the piston through the remainder of the stroke, but with diminishing force. Although less work would be done, still less steam would be used, hence the fuel saving. At first the economies resulting were very small, but as steam pressures increased, the practice of expansive working became all-important, forming the basis for the highly efficient compound engines of the late nineteenth century.

Watt's third 1782 patent was a second best, an attempt to circumvent another idea patented 2 years earlier and possibly stolen from him by one of his own workmen. The idea of developing the steam engine to provide rotary power and thus drive machinery was exercising the minds of several engineers in the 1770s and early 1780s. The far-seeing Boulton was well aware of the huge new market that the 'rotative' steam engine could tap and pressed Watt hard to produce a satisfactory design. It is characteristic of the two that Boulton, the enthusiastic businessman, should write in 1781 '... the people in London, Manchester, and Birmingham are *Steam mill mad*...' and that the dour Watt should grumble in the following year '... surely the devils of rotations is afoot'. The problem was to adapt the simple reciprocating movements of the beam engine to produce rotary power. Nowadays one would imagine nothing could be simpler than the use of the common crank to connect the end of the beam to a rotating shaft, and even in Watt's time the crank was a well known mechanism in everyday use on the foot lathe and spinning wheel. What was not appreciated, however, was the fact that the variable stroke of the beam engine, which Watt at first feared would wreck any attempt to adapt it to rotary motion, would be controlled and regulated by using a connecting rod, crank and flywheel. Unfortunately for Watt another engineer, James Pickard of Birmingham, patented the crank first in 1780 after using it to replace an unsatisfactory rack-and-pinion drive to a rotating shaft. Watt held numerous patents himself and suffered throughout his life from others infringing them. Instead of contesting Pickard's patent, he thought it politic to devise a substitute. The result was the sun-and-planet or epicyclic gear in which the 'planet' wheel, fixed rigidly to the end of the connecting rod, is made to move round the perimeter of a 'sun' wheel keyed to the driven shaft. A property of this gear is that the flywheel will revolve twice for every double stroke of the piston, something of an advantage with the early and slow-moving engines. The

gear was used until 1802 although Boulton & Watt built engines with cranks before and after the expiry of Pickard's patent in 1794.

Two further Watt inventions are worthy of note, particularly as they cover features familiar on almost all the beam engines surviving today. In 1784 Watt solved the problem of a satisfactory connection to transmit the simple up-and-down movement of the piston rod to the end of the beam, which described a segment of an arc. The 'parallel motion' devised by Watt combined the three-bar motion and the pantograph in a most elegant way and Watt himself stated that he was more proud of this invention than any of his others.

To ensure steady motion of the engine under variable load conditions, Watt introduced, in 1787, the conical pendulum centrifugal governor, consisting of two balls which flew outwards as speed increased to move a sleeve which by linkage controlled a butterfly valve in the steam pipe. Watt neither claimed this invention as his own nor attempted to patent it, as it had already been used in flour mills to regulate the speed and distance apart of millstones.

With the advent of rotary power generated by steam, industry was on the verge of a major technological breakthrough. By 1800, when Watt's partnership with Boulton ended and the patent on the separate condenser expired, 496 engines had been built, of which 308 were rotative. A few of these were rated at 40 hp but most had an output of between 15 and 20 hp, well within the capacities of the major prime mover in use at that time, the waterwheel. The main advantages of the steam engine, however, were its freedom from siting problems and unreliability of water flow, which restricted the widespread application of water power. Indeed Matthew Boulton's first interest in the steam engine was aroused by the lack of water for driving waterwheels in summer, the 'thirsty season'.

The distribution of Boulton & Watt engines, drawn up from the very full records of the firm's trading now housed in the Birmingham Reference Library, provides an indication of the impact of steam power on industry in the last quarter of the eighteenth century. It shows a wide dispersion both geographically and in terms of the variety of industries in which the engines were used. The poor representation of Watt engines at collieries is to some extent misleading, however, as the coal industry had actively taken up the Newcomen engine for pumping purposes and, as fuel costs were not an

important factor, there was little incentive to change. Thus in the Northumberland-Durham coalfield, which had fifty-seven Newcomen type engines in 1769, only six Boulton & Watt engines were in use by 1800.

Those industries able to take greatest advantage of the rotative engine did so enthusiastically. Cotton mills, woollen and worsted mills, flax mills, textile finishing works, forges and foundries, metal workshops, pot banks and glassworks, corn mills, breweries and distilleries, canals and waterworks were all using steam to some extent by 1800. Over one-third, 114 engines, were in use in the textile industry and cotton alone accounted for ninety-two of these. Next were ironworks, with a total of thirty-seven engines, followed by collieries with thirty-three mainly for pumping, while corn mills, breweries and distilleries together employed thirty-nine engines. As Watt had a virtual monopoly of steam power until 1800, these figures represent fairly accurately the relative degree of penetration of steam power into industrial activity in Britain. The geographical distribution, shown in Fig 7, is just as interesting, illustrating the early establishment and relative importance of the industrial areas we know today. Only Shropshire and Cornwall, where the iron and tin industries respectively have declined, are over-represented in terms of today's pattern of industrial distribution. A total of fifty-five engines were in use in Lancashire, largely in the cotton industry. The next highest total, of forty-one, was in Middlesex, demonstrating the enormous, and often overlooked, significance of London as an industrial centre.

The beam engine enjoyed greatest popularity for driving machinery between 1800 and 1860, but in both its rotative and non-rotative forms it was in vogue for water and sewage pumping until the early 1900s. Few non-pumping engines are still in active use, although a number are preserved. An early example of a Watt engine, dating from 1788 and complete with sun-and-planet gear, wooden beam and centrifugal governor, may be seen in the Science Museum, South Kensington. A pair of beam engines still in regular use drive mashing and milling machinery in the Ram Brewery, Wandsworth (170/TQ 256747). Built by Wentworth & Sons in 1835 and 1867 these compound engines exhibit all the classic features, including slide valves, lattice eccentric rods (introduced by Murdock in 1799), cast-iron beams, timber-lagged cylinders and the immaculate cleanliness so typical of steam engine maintenance.

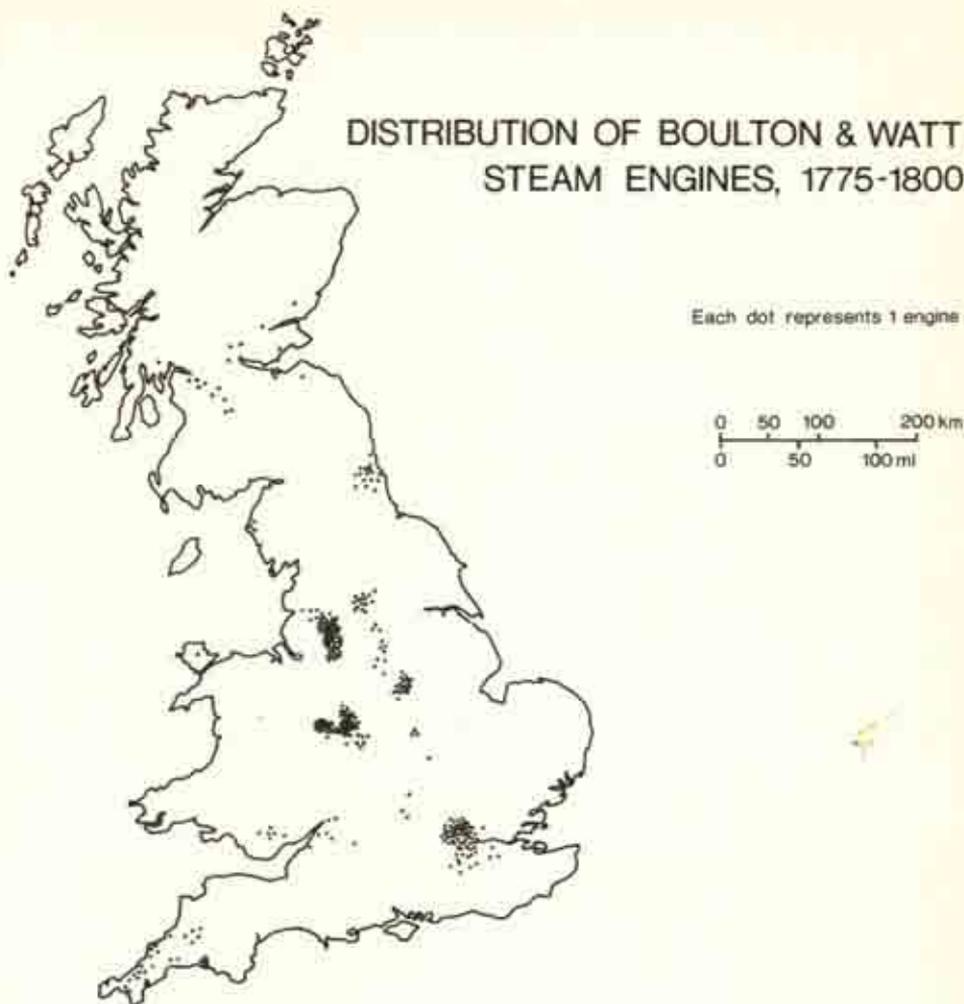


Fig 7

The mechanical fascination and tremendous visual impact of the large beam engine has led to numerous examples being preserved *in situ*, although all too few are in steam. At Stretham in Cambridgeshire (135/TL 517730) one survives for fen drainage. Installed in 1831 by the Butterley Company of Derbyshire, it has a single cylinder of 39in diameter and 8ft stroke and developed 105 hp at 13 to 16 rpm. A scoopwheel (Plate 11) acting, in effect,

## TYPES OF STEAM ENGINE 1 SHOWING WORKING PARTS ONLY

### Newcomen atmospheric beam engine

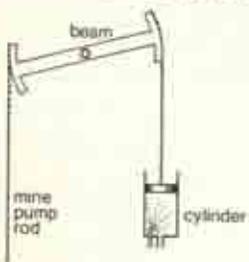


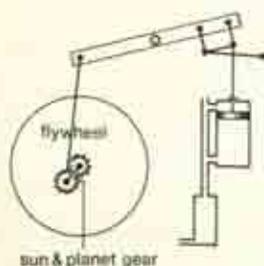
Fig 8 A Developed for mine pumping, the Newcomen engine used the pressure of the atmosphere for its power stroke. A partial vacuum was created in the cylinder beneath the piston by condensing the steam with a cold water jet.

### Watt single-acting beam engine



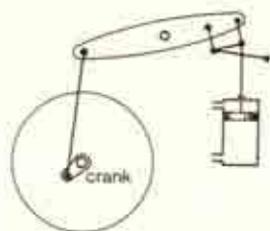
B In Watt's engine the efficiency was improved by condensing the steam in a separate vessel — the separate condenser — thus avoiding the alternate heating and cooling of the cylinder. The engine was still only for pumping.

### Watt double-acting rotative beam engine



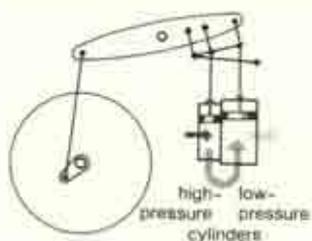
C In the rotative engine — the first heat engine to drive machinery — a number of new features were introduced. The piston had steam pressure applied to both top and bottom, making the engine double-acting. A linkage — the parallel motion — connected piston rod to beam. The other end of the beam drove a flywheel through a connecting rod and sun-and-planet gear.

## Single-cylinder rotative beam engine



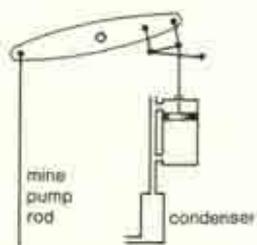
D After about 1800 the Common crank was almost universally used for the drive from the beam and connecting rod. Beam engines of this type were built in large numbers for driving all types of factory machinery down to the 1880s

## Woolf compound beam engine



E Efficiency was still further improved by compound expansion using a high- and low-pressure cylinder both at the same end of the beam. Woolf compound engines were widely used in water pumping stations and to a lesser extent in small factories

## Cornish beam engine



F The Cornish engine was a highly efficient single-acting development of the non-rotative beam pumping engine, and was used extensively in tin mines. Developed by Richard Trevithick it used high-pressure steam, expansive working and condensation to obtain maximum economy

## TYPES OF STEAM ENGINE 2 SHOWING WORKING PARTS ONLY

### McNaught compound beam engine

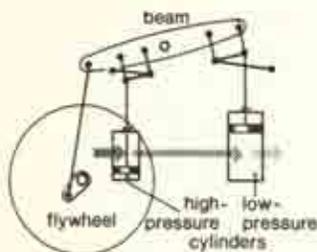
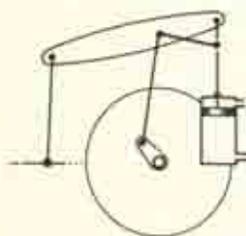


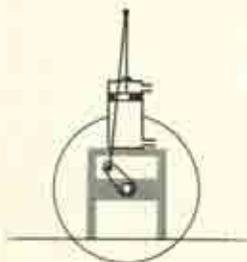
Fig 9 A Patented in 1845, the McNaught principle consisted initially of the addition of a high-pressure cylinder to the flywheel end of an existing beam engine, thus deriving compound expansion and reducing stress. Later many large beam engines were built in this form

### Grasshopper engine



B The grasshopper engine was usually small and compact, based on a single bed-plate, allowing easy installation. The beam was pivoted at one end instead of at the centre, and the drive to the connecting rod was taken off at an intermediate point near the piston rod end

### Maudslay table engine



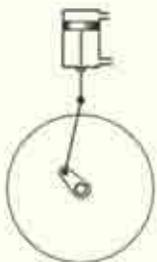
C Maudslay's table engine also had the advantage of compactness and ease of installation. The beam was dispensed with altogether and a direct connection made between the vertical piston rod and the crankshaft mounted at a low level below the cylinder. It was widely used as a small factory power unit

## Single-cylinder vertical engine



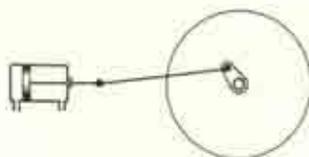
D In the single-cylinder vertical engine the drive was similar but the crankshaft was mounted vertically above the cylinder. The type was used in factories and mills and for colliery winding particularly in the North East

## Single-cylinder inverted vertical engine



E The inverted vertical single-cylinder engine, introduced in the 1840s, was rarely large. The type was particularly common for small factories and, with reverse gear, for marine applications. Later versions had enclosed crankcases and forced lubrication

## Single-cylinder horizontal engine



F Perhaps the most common simple type of steam engine, the single-cylinder horizontal was built in large numbers in the second half of the nineteenth century. Most had slide valves, were non-condensing and the compact cast-iron bed made them easy to install

Horizontal tandem-compound engine

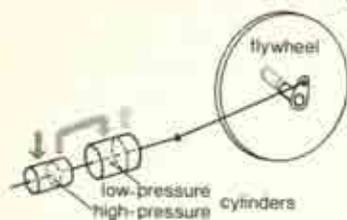
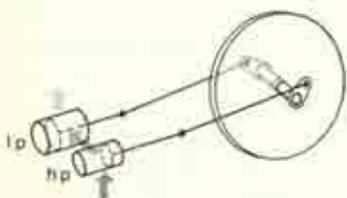


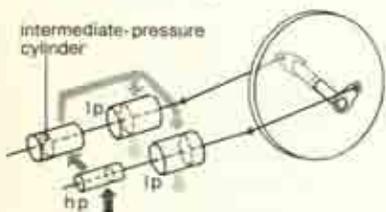
Fig 10 A A logical development from the single-cylinder horizontal was the tandem-compound in which high- and low-pressure cylinders were mounted one behind the other on the same piston rod. Highly sophisticated, tandem compounds of medium power output were built for textile mills

Horizontal cross-compound engine



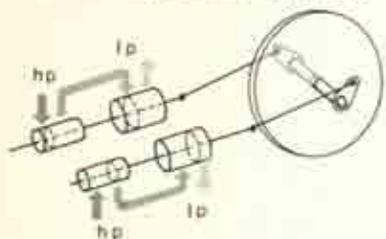
B Another means of compounding the horizontal engine was to have high- and low-pressure cylinders side by side driving each end of the crankshaft. Many mill engines were of this type, the drive being taken off the flywheel rim between the two cranks

Horizontal triple-expansion engine



C A development of the compound principle involved three stages of expansion. Steam passed from a high-pressure to an intermediate-pressure cylinder on the other piston rod and thence to a pair of equal diameter low-pressure cylinders, one on each side of the engine

Horizontal twin tandem-compound engine

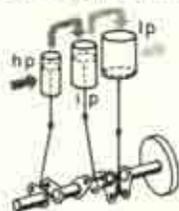


D The twin-tandem compound consisted simply of two tandem compounds driving a single crankshaft. Like the other compound and multiple expansion engines, this type became highly developed for powering textile mills

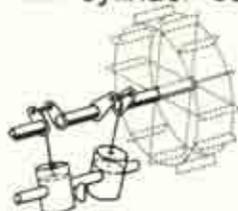
## Vertical compound engine



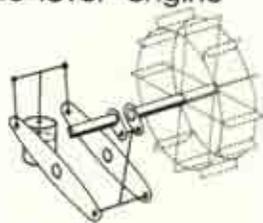
## Vertical triple-expansion engine



## Twin-cylinder oscillating engine



## Side-lever engine

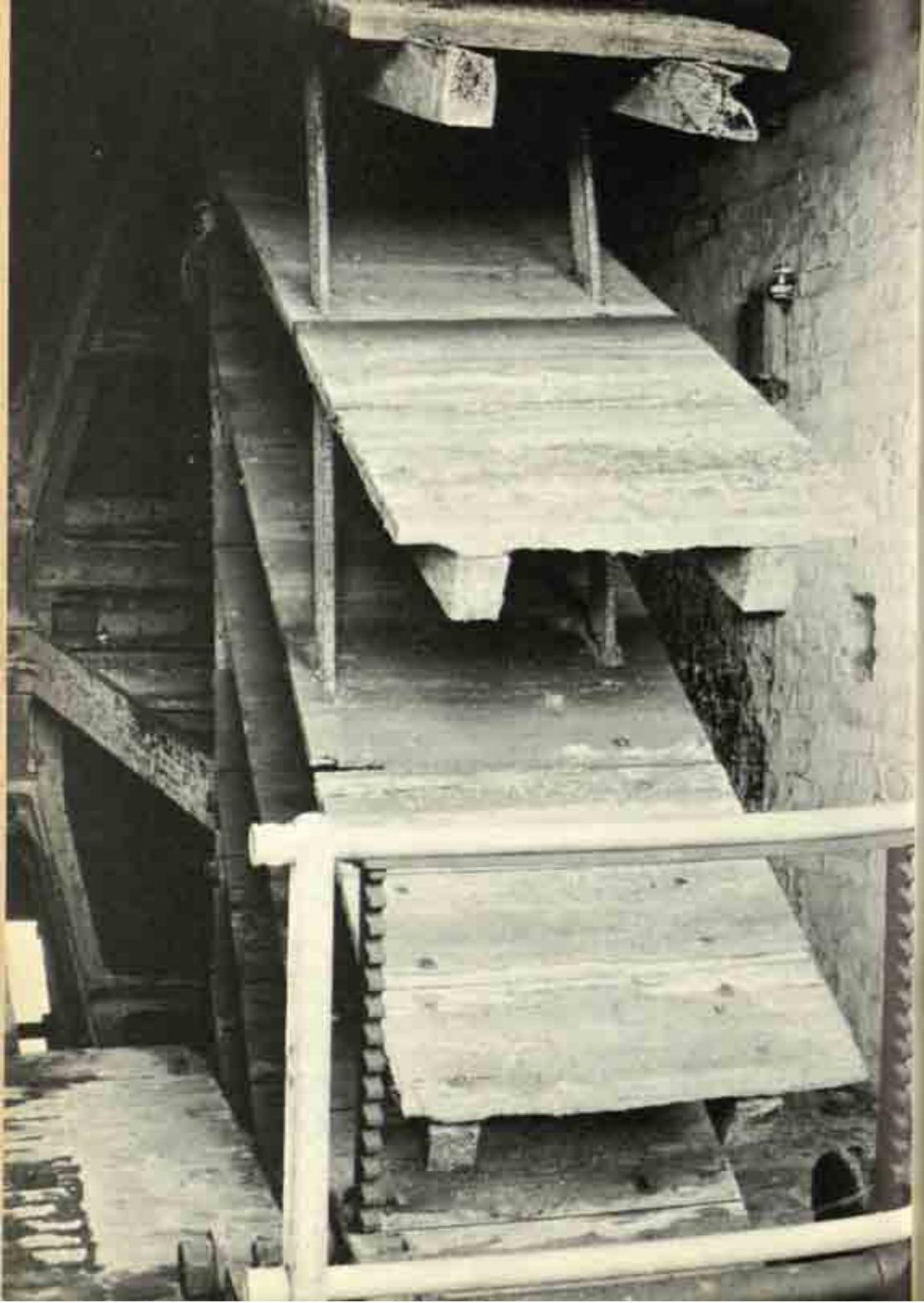


E In its simplest form the vertical compound was used mainly in ships, but a small enclosed-crankcase high-speed type, developed from the end of the nineteenth century, became popular for generating electricity

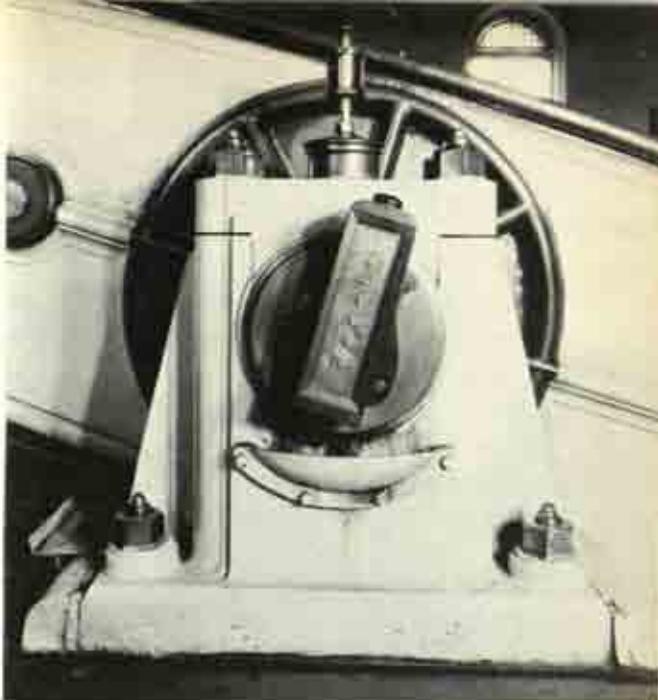
F Vertical triple-expansion engines were almost universally used in large ships before the introduction of steam turbines. On land they became the generally accepted successors to beam engines for water and sewage pumping

G The oscillating engine, in which rocking cylinders were mounted on trunnions formed from the steam inlet and exhaust pipes, had no connecting rods, the piston rod being attached directly to the crank. Their compactness made them particularly suited for use in paddle steamers

H The side-lever engine with its low centre of gravity was designed for marine application and was used extensively in paddle steamers before 1850. It was basically a beam engine with the beam pivoted at a low level,



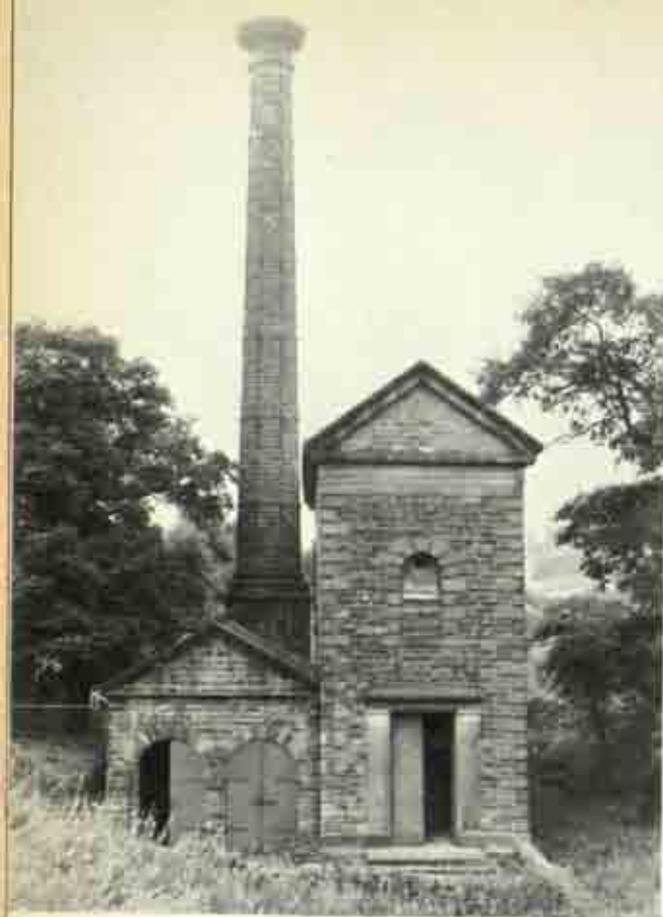
12 Papplewick pumping station, Notts. Detail of beam trunnion with engine stroke counter



like a waterwheel in reverse lifted some 30 tons of water at each revolution. The original wheel was 28ft in diameter but this was increased to 33ft in 1848. The engine last operated in 1941 and is now under the care of the Strettham Engine Preservation Trust.

The robust reliability of the beam engine made it popular with water supply companies and for sewage pumping, and in these roles it reached a high degree of development by the latter years of the nineteenth century. Two late engines of this type are preserved at Papplewick, Nottinghamshire (112/SK 583522). Built by James Watt & Co in 1884, these rotative engines (Plate 12), with their 46in diameter cylinders and 7ft 6in stroke, each raised 1,500,000 gallons of water per day from the Bunter sandstone to supply the city of Nottingham. The iron pillars supporting the engine are covered in intricate decoration, which recurs throughout the interior of the engine house in tilework and stained glass windows. The whole effect is heightened by the landscaped setting and ornamental pool beloved of waterworks companies at this period. Also preserved in the East Midlands are four sewage pumping engines at Abbey Lane, Leicester (121/SK 589066).

11. Strettham pumping station, Cambridgeshire. Detail of scoop wheel



13 Cromford pumping station, Derbyshire

built in 1891 by Messrs Gimson, a local firm. They form the centrepiece for a museum of technology of the East Midlands, currently under active development. In County Durham, Ryhope pumping station near Sunderland (78/NZ 403523), with its two 1868 rotative compound engines by Hawthorns of Newcastle, is under the care of the Ryhope Pumping Engines Preservation Fund, while in Hampshire, Portsmouth City Museums are restoring two sewage pumping engines of 1887 at Eastney (181/SZ 675989).

A specialised, and in many cases very large, type of beam engine was the Cornish pump (Fig 8) developed by Richard Trevithick (1771-1833) from an engine erected in 1812 at Wheal Prosper tin mine at Gwihian in Cornwall. The Cornish engine operated at a much higher pressure than contemporary

Watt engines, usually about 50 lb per sq in, and used expansive working to gain high efficiency. It was a single-acting, usually non-rotative beam engine in which steam applied above the piston lifted, through the beam, pump rods in the mine shaft. The sequence of operation was then as follows:

With the piston at the bottom of the cylinder the equilibrium valve was opened, allowing steam to be transferred from the upper to the lower side of the piston as the unbalanced weight of the pump rods caused the piston to ascend.

When the piston was at the top of the stroke the equilibrium valve was closed and steam admitted above the piston.

At the same time the eduction valve at the bottom of the cylinder opened to the condenser.

Thus the power stroke was effected using steam pressure on top of the piston and a partial vacuum below caused by condensation of steam in the condenser.

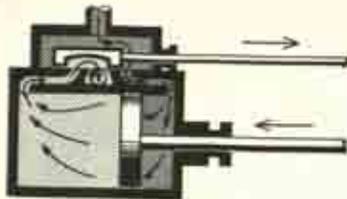
Cornish engines were extensively used for draining mines and also found widespread favour for water supply pumping and other drainage applications, as in the Severn railway tunnel. The increase in thermal efficiency over Watt engines was enormous with 125 million foot/pounds per bushel claimed in 1834 from an engine with an 80 in diameter cylinder as compared with the 20 millions normally attained by the low pressure engines.

As their name suggests, they were most numerous in Cornwall, where five engines were preserved by the Cornish Engines Preservation Society and are now in the care of the National Trust. These include one of the largest, built in 1892, with a 90in diameter cylinder, at Taylor's shaft, East Pool (189/SW 674416), and an early rotative winding engine of 1840 at Levant Mine (189/SW 375346), 6 miles from Land's End. In Scotland the Cornish engine at Prestongrange Colliery, East Lothian (62/NT 374737), built by Harvey & Co of Hayle, Cornwall, in 1874, is being restored to form the centre of a historical site devoted to the Scottish coal industry. Last worked in 1954, this pumping engine has a steam cylinder 70 in in diameter with a stroke of 12ft.

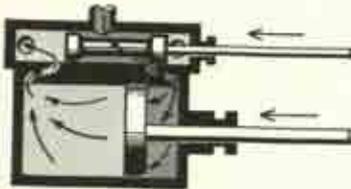
Crofton on the Kennet & Avon Canal in Wiltshire (167/SU 262623) has the oldest engine in the world still to operate on steam. The pumping

■ steam from boiler    ■ exhaust

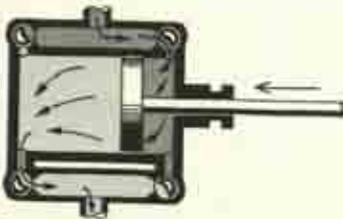
## STEAM ENGINE VALVES



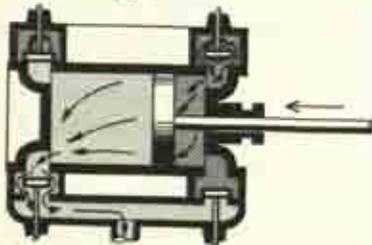
Slide valve



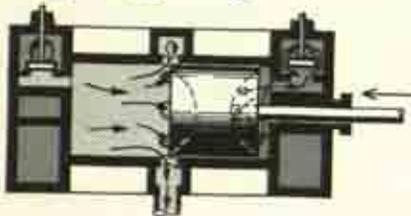
Piston valve



Corliss valve



Drop valve



Uniflow engine

## Fig 11 Steam Engine Valves

### *Slide valve*

The slide valve, invented in 1799 by William Murdock (1754-1839), consisted of a metal box sliding on a flat face in which were cut the steam inlet and exhaust ports. Steam was usually admitted at the ends and exhausted through a central port under the hollow box valve, as shown in the example illustrated. Steam pressure thus helped retain the valve in contact with the face.

### *Piston valve*

Like the slide valve, the piston valve was a single unit controlling steam inlet and exhaust. It consisted of a pair of pistons on a single spindle moving in a cylindrical bore that had inlet and exhaust ports in its sides. As the valve spindle moved backwards and forwards in the steam chest, the appropriate ports were uncovered to admit and exhaust steam. Both slide and piston valves had the disadvantage of steam being admitted and exhausted through the same channels, with consequent loss of efficiency resulting from alternate heating and cooling.

### *Corliss valve*

The Corliss valve had none of these disadvantages, as a separate inlet and exhaust valve was provided at each end of the cylinder. Developed by the American George H. Corliss (1817-88) and patented in 1849, this type of valve became widely used on large mill engines. Each valve consisted of a barrel that partially rotated in a bored chamber to uncover the steam port. The inlet valves were opened by the valve rods against a dashpot. At the cut-off point the valve was released by trip gear to be closed rapidly by the dashpot.

### *Drop valve*

Drop valves had turned circular faces fitting into valve seats in the steam chests. Valve and seat were ground together to ensure that they were steamtight. There were four valves per cylinder, the inlet valves being raised to admit steam and dropped by a trip gear to provide instantaneous admission cut off. Both Corliss and drop valves gave very economical steam consumption and steady governing, essential in driving textile machinery.

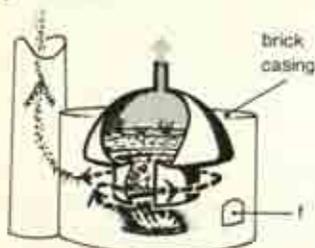
### *Uniflow engine*

In the uniflow engine only admission valves were provided, as exhausting the steam was achieved by the piston at the end of its stroke uncovering a ring of ports in the wall of the cylinder. Although there were manufacturing difficulties with the uniflow type, it was highly efficient because there was no alternate heating and cooling of the cylinder ends by steam being admitted and exhausted through them.

# TYPES OF BOILER

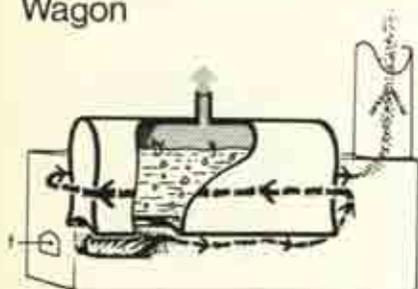
CUT OPEN TO SHOW INTERIORS

## Haystack



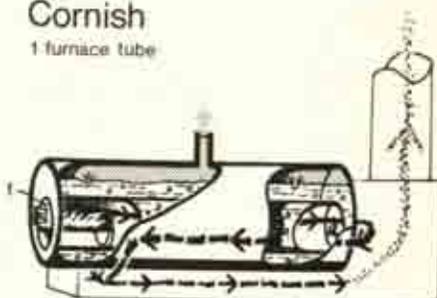
-  steam
-  water
-  flow of hot combustion gases through boiler
-  flow of hot combustion gases in brick flues along outer surface of boiler, giving extra heating
-  smoke to chimney
-  firehole door(s)

## Wagon



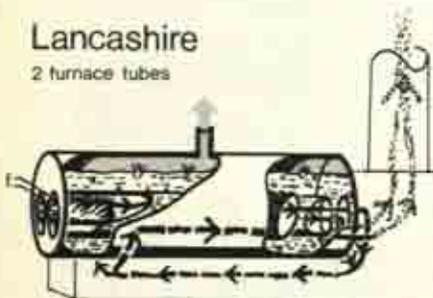
## Cornish

1 furnace tube



## Lancashire

2 furnace tubes



## Fire-tube

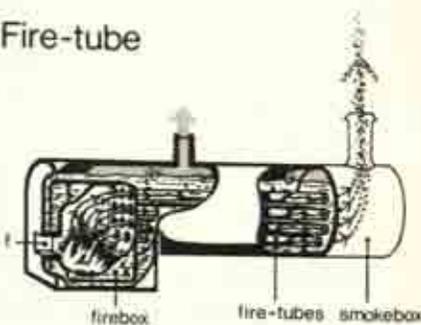


Fig 12



14 Haystack boiler, Blists Hill Open Air Museum, Ironbridge, Shropshire

station was begun in 1803 and designed to supply the 35 mile section of the canal between Bedwyn and Seend with water lifted some 40 ft out of Wilton Water. The first engine began pumping in November 1809. It was built by Boulton & Watt in 1801 for the West India Dock, London, but was diverted to the canal company in 1802. On the initiative of John Rennie, the engineer for the canal, a more powerful engine was ordered from Boulton & Watt and began work in 1812. Originally both engines were of the single-acting atmospheric type operating at about 5 lb per sq in steam pressure and using Watt patented separate condensers, but in 1844, in an effort to increase efficiency, they were converted to the Cornish cycle of operation by Messrs Harvey of Hayle, Cornwall, with new boilers providing steam at 20 lb per

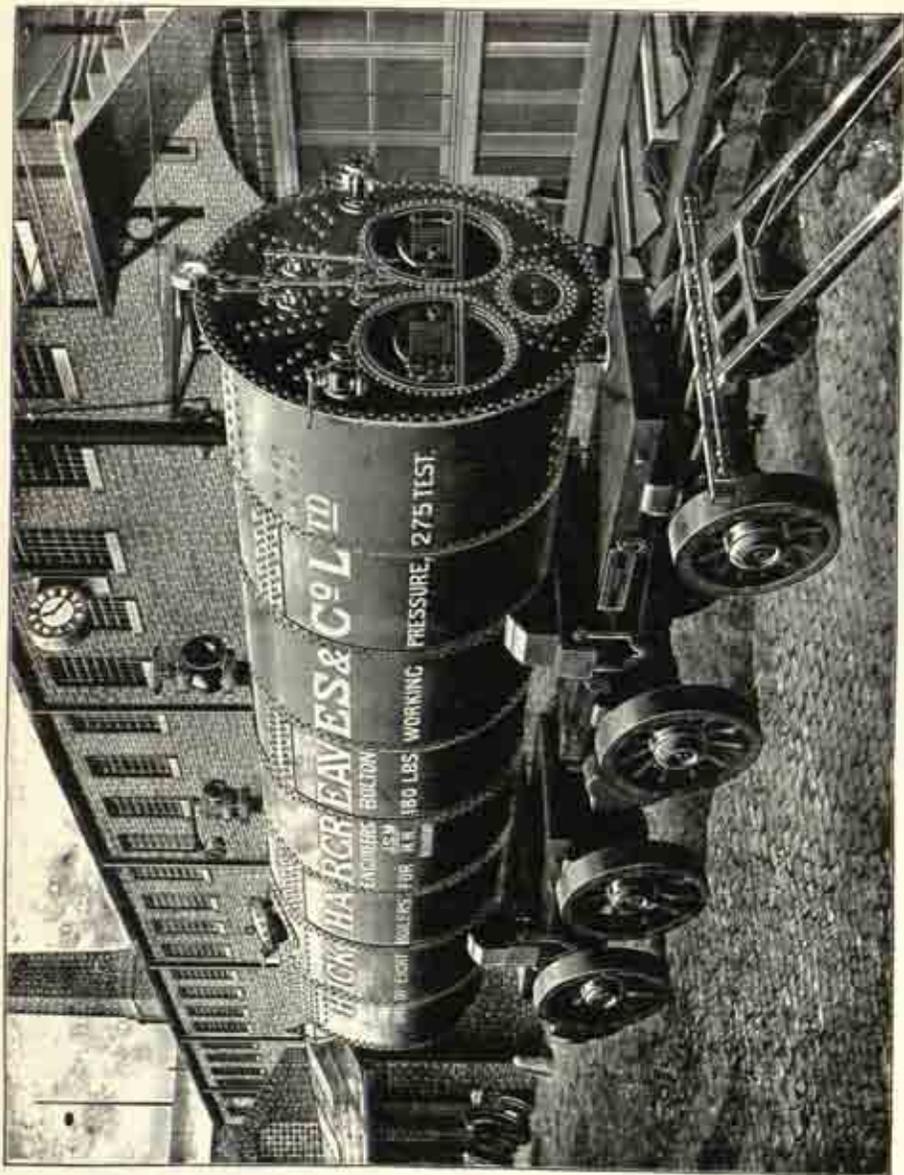


Fig 13 Lancashire boiler for 3,000 ihp triple-expansion engines

sq in. Later, in 1844, a Sims Combined Engine was installed to replace the 1801 machine, but this gave considerable trouble and was rebuilt in 1905 as a simple condensing engine, with a new 42 in cylinder. The 1812 Boulton & Watt engine has been restored to working order and is doing the work for which it was originally installed. It can be seen every Sunday and is in steam on selected weekends throughout the year. Restoration of the second engine is in progress.

The higher steam pressures at which the Cornish engine operated demanded stronger boilers (Fig 12) than the 'haystack' (Plate 14) or 'wagon' types which were used with Newcomen and Watt engines. The earliest haystack boilers were made of copper with a lead top, but after about 1725 hammered wrought-iron plates were used. The wagon boiler used by Watt had a similar cross-section to the haystack but was elongated to give more heating surface. Its rectangular shape was also easier to make. Neither was suitable for pressures in excess of 10 lb per sq in, so about 1812 Trevithick developed a cylindrical boiler with a grate set at one end of an internal tube running through its length. At the rear the hot gases divided and passed forward in brick flues along each side before returning beneath the bottom to the chimney. These Cornish boilers, as they came to be called, generated steam at some 50 lb per sq in and were widely adopted as high-pressure steam engines spread. They remained popular until the introduction of the Lancashire boiler (Fig 13) after 1844. In that year William (later Sir William) Fairbairn (1789-1874) and John Hetherington of Manchester patented a cylindrical boiler with two flues, devised, as Fairbairn stated, 'with a view to alternate firing in the two furnaces in order to prevent the formation of smoke', but also, of course, providing a substantially increased heating surface. Lancashire boilers are still in common use and examples may be seen in association with most of the preserved engines already mentioned. The Cornish boiler has almost completely disappeared, but Trevithick's 1812 original is preserved at the Science Museum, South Kensington. Many boiler shells of both Cornish and Lancashire types may be seen converted for use as oil storage tanks.

The opening years of the nineteenth century saw several alternatives to the beam engine introduced to achieve greater thermal and mechanical efficiency, higher speeds and simplicity of erection. This last factor was of some importance as the cumbersome beam engine required skilled engineers to

assemble it on site, was not easily adaptable to the often rapid rate of development of factories, could not easily be resited and took up a lot of space. Thus relatively portable self-contained direct-acting engines, dispensing with the heavy rocking beam between connecting rod and crankshaft, began to appear in increasing numbers. An early form was the table engine (Fig 9) introduced in 1807 by Henry Maudslay (1771-1831) and this was followed after about 1825 by numerous designs of the soon to be popular horizontal engine having a single cylinder, slide bars and crankshaft bearings on a cast-iron bedplate of box-girder section. In the table engine the vertical cylinder of the beam engine was retained but the piston rod drove a crankshaft beneath by means of two return connecting rods. Its portability made it popular until the middle of the nineteenth century for driving workshops, but it has now almost completely disappeared. An example may be seen at the Science Museum.

The horizontal engine was introduced as early as 1802 by Richard Trevithick as one of a number of his experimental designs using high-pressure steam. Another high pressure design by Trevithick, but employing a vertical cylinder, is preserved in the Science Museum. The horizontal engine (Fig 9) was little exploited until after 1830 and did not become widespread until the 1850s. After this date, however, simple single-cylinder horizontal engines were produced in large numbers for use in breweries, saw mills, small engineering shops and many places where an easily maintained power unit was required. Firms such as Tangye of Birmingham made standard designs in a variety of sizes which could be installed either as a single cylinder version or with two identical cylinders, one on each side of the flywheel. An example of this latter type dating from 1885 is still used to power the Port of Bristol Authority workshop at Underfall Yard, Bristol (156/ST 572722).

The direct-acting vertical engine (Fig 9) with the crankshaft above the cylinder was patented in 1800 by Phineas Crowther of Newcastle-upon-Tyne but its only widespread application seems to have been for colliery winding in the Northumberland and Durham coalfield. One remaining example is preserved at Beamish Colliery (78/NZ 220537) under the care of the North of England Open Air Museum. The inverted vertical engine (Fig 9) with its crankshaft immediately below the cylinder was introduced in the 1840s by James Nasmyth (1808-90) as a logical derivation of his steam

hammer design of 1839. It achieved considerable popularity as a small power source, particularly in the marine application of driving screw propellers. Various types of supports for the cylinder can be found, ranging from a single-side cast-iron frame with or without a turned steel column at the open side to a symmetrical 'A' shaped casting. Later versions, built in large numbers well into this century, have the connecting rod and crankshaft completely enclosed, in the same manner as a motor car engine, and operate at high speeds with pressure lubrication.

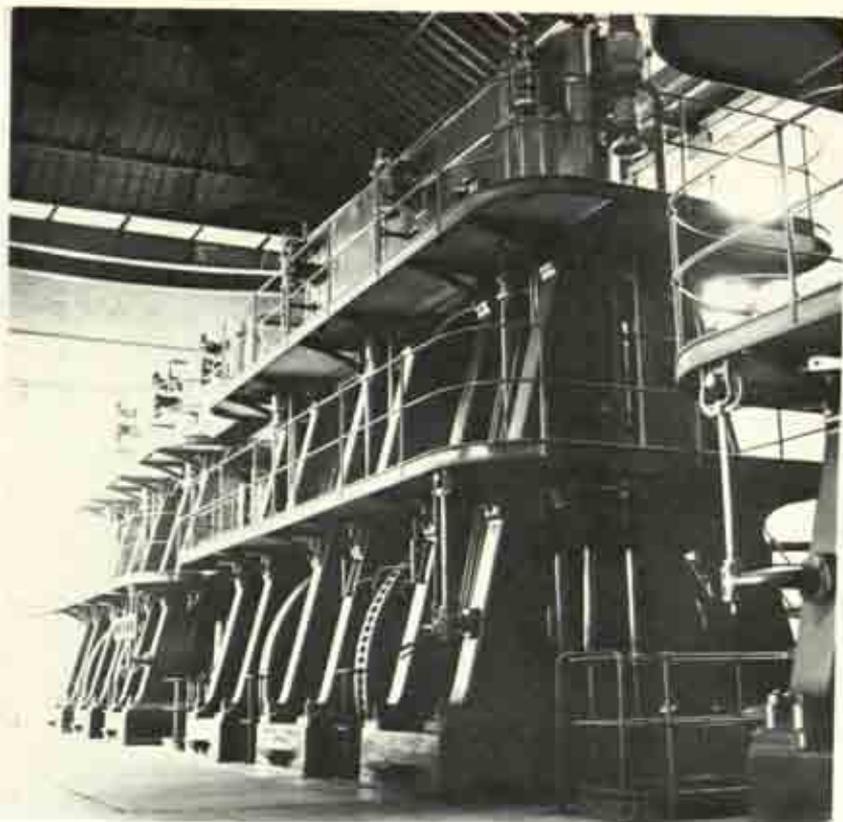
Despite this profusion of new engine layouts during the nineteenth century, the beam engine continued to be built with various modifications and one or two ingenious adaptations. One of these was the grasshopper engine (see Fig 9) patented in 1803 by William Fremantle, the same principle being employed by Oliver Evans in America at about the same time. In this design the piston rod was connected by a pin to one end of the beam while the other end was supported on two long back links which allowed it to rock backwards and forwards. The centre of the beam was constrained by radius arms and the drive to the connecting rod taken off at a point between the centre and the piston rod link. The major advantage of the engine was one of compactness. Another beam engine variant, introduced in 1805 by Matthew Murray (1765-1826), had the beam centred below the cylinder and crankshaft. Side rods connected the piston rod to one end of the beam while the other had a connecting rod driving upwards on to the crank. Its low centre of gravity made the engine (Fig 10) popular in paddle steamers, and an example may be seen in the tug *Reliant*, built in 1907 by J. T. Eltringham & Co of South Shields, and on view in the Neptune Hall of the National Maritime Museum at Greenwich.

By far the most significant advance in steam engine design in the nineteenth century was the introduction of the compound or multiple cylinder expansion principle, initially applied to the beam engine and later providing the basis for a wide variety of highly efficient direct-acting engines. As early as 1781 Jonathan Hornblower (1753-1815) had patented an engine with two cylinders in which the steam was introduced to the first direct from the boiler and was exhausted into a second cylinder of larger diameter where it continued to expand and do useful work on the piston. It was not found to be significantly more efficient than the contemporary Watt engine, but in 1804 Arthur Woolf (1776-1837) revived the idea using high-pressure

steam. Although reasonably successful, Woolf's engines (Fig 8) were not widely adopted, being more expensive and complicated than the Cornish engines of Trevithick with which they were compared. In 1845, however, William McNaught of Glasgow introduced an ingenious and highly successful method (Fig 9) of compounding by adding a smaller diameter high-pressure cylinder on the crank side of the beam of a conventional beam engine, between its centre and the connecting rod. This avoided overstressing the beam and, by replacing the old low pressure boiler with a high pressure one, both power and economy were improved without the need for a completely new engine. By the 1860s compound beam engines were widespread and new engines were being built in the Woolf manner with cylinders side-by-side driving on to the same end of the beam. Compounding enabled steam to be expanded in the cylinders to many times its original volume with minimal losses from condensation and leakage. The Ryhope engines mentioned above are typical compound beam engines.

With high-pressure direct-acting engines, compounding (Fig 10) was still more successful, eventually being achieved in three and even four stages through cylinders of successively increasing volume. The triple-expansion type with three cylinders mounted vertically and driving on to the crankshaft below found favour for marine use and also as a replacement for beam engines in water pumping stations. Two of the largest land-based triples (Plate 15) ever built are still in use at Kempton Park Waterworks, Honnslow (170/TQ 110709), while another pair have recently ceased operation at Otterbourne pumping station in Hampshire (168/SU 468233); both sets were built by Worthington Simpson of Newark and date from the 1920s.

By the end of the nineteenth century the big textile mills of Lancashire and Yorkshire were demanding higher and higher hps to drive their vast numbers of machines and a specialised type of engine, the mill engine (Fig 14) was developed to satisfy this need. These engines were almost invariably horizontal compounds and some were designed to produce as much as 4,000 hp. The two most popular layouts were the tandem-compound in which the high and low pressure cylinders lay one behind the other with a common piston rod, and the cross-compound in which the high pressure cylinder drove one end of the crankshaft and the low pressure the other. Between the two was the flywheel with its broad face cast in grooves for the cotton drive-ropes that powered the mill. The engine of Dee Mill, Shaw,



15 Kempton Park Waterworks: two of the five triple-expansion pumping engines built by the Lilleshall Company in the early 1900s

near Rochdale (101/SD 945093), is an example of the ultimate in mill engine design. It is a twin-tandem compound, that is it has two piston rods each with a high and low pressure cylinder driving each end of the crankshaft. Built in 1906 by Scott & Hodgson Ltd of Guide Bridge, the 'Dee' engine has two 18 in diameter high pressure cylinders with Corliss semi-rotary valves and two low pressure cylinders of 42in with piston valves. It is preserved by the Northern Mill Engine Society in association with the owners, Courtaulds Ltd. A small tandem-compound mill engine by Pollitt & Wigzell of Sowerby Bridge is displayed in the Birmingham Museum of Science & Industry.

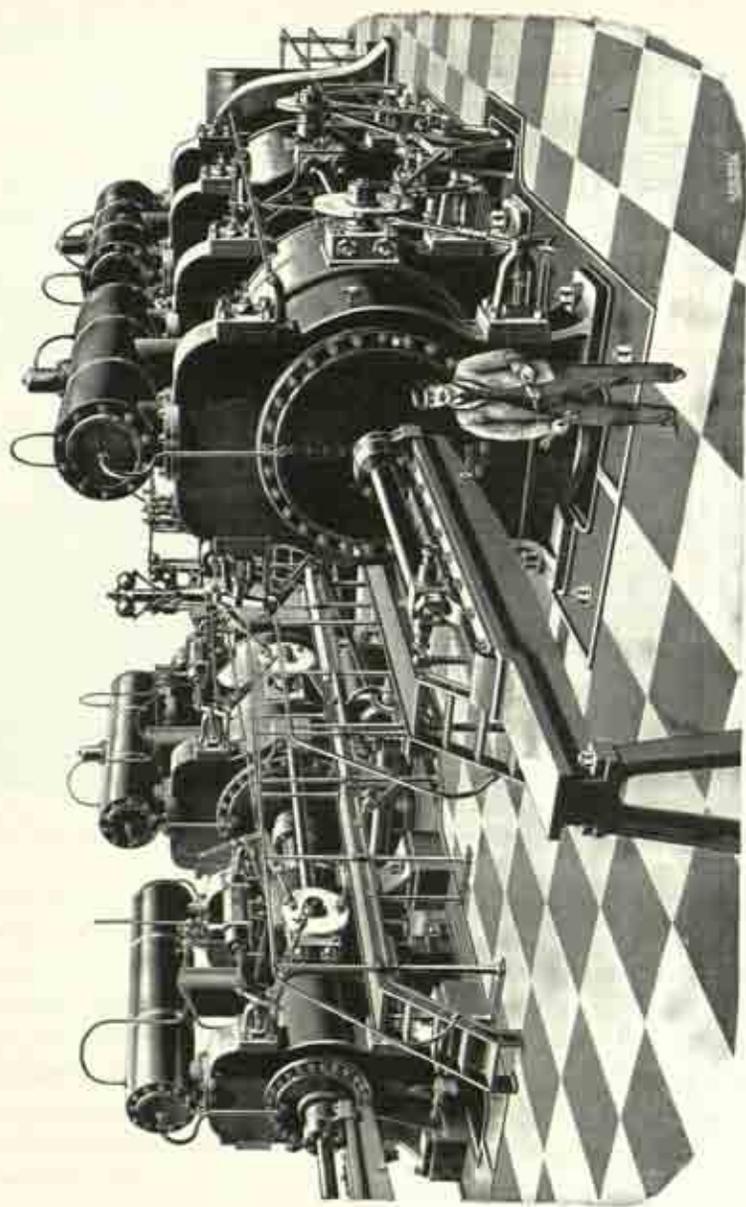


Fig 14 3,000-hp triple-expansion mill engine — Hick, Hargreaves and Co Ltd, Bolton

In the 1880s a new demand arose for engines to power electrical dynamos. At first slow-speed engines were used to drive dynamos by belt but the advantages of direct coupling led to the introduction of a specialised type of engine capable of running at speeds in the region of 500 rpm. A number of these were made single-acting to avoid the reversal of load on the crankpin and thus eliminate the knocking which would develop unless impractically small bearing clearances were used. The most successful and widely adopted design of this type resulted from patents taken out in 1884 and 1885 by Peter William Willans (1851-92) for a central valve engine in which the steam was distributed by a piston valve inside the hollow piston rod. The valve was worked by an eccentric on the crankpin and the engine, which was a vertical, had a totally enclosed crankcase with splash lubrication. Simple, compound and triple expansion types were made in large numbers and ultimately in sizes up to 2,500 hp. Although extremely economical, they have almost completely disappeared from use and examples are much more difficult to find than are beam engines. Willans engines can be seen in the Science Museum, South Kensington and the Guinness Museum, St James's Gate, Dublin.

The introduction of the steam turbine in the 1880s and its rapid development in the following years rendered the Willans engine obsolete by the early 1900s, but another type of high-speed reciprocating engine was also rivalling it by that date. This came from the Bellis & Morcom company of Birmingham, which introduced a double-acting enclosed vertical engine in the mid-1890s in both compound and triple-expansion form, largely for powering small generators. It had forced lubrication and was extremely efficient. Large hp versions were built, up to 2,500 hp, but these could not compete with turbines. In small sizes, however, the Bellis & Morcom type of engine, made by a variety of manufacturers, is still used particularly in hospitals and laundries where low pressure steam is required for heating or process work. By generating steam at a high pressure and feeding it first through an engine, electricity can be generated at very small additional cost.

Before turning to the steam turbine and its development, let us consider a number of other types of reciprocating engine that may frequently be encountered by the industrial archaeologist in a variety of applications. So far we have dealt mainly with large engines designed for powering factories

or major installations such as water pumping stations, but numerous steam engines were produced after about 1870, and well into the present century, to provide relatively small amounts of power at almost any point where it was needed. The most popular of these was based on the locomotive type of boiler on which the engine itself was mounted. Its most mobile form was the traction engine, consisting of a single-cylinder, or twin-cylinder compound, horizontal engine providing power both to move the engine and to drive machinery such as threshing machines. A similar type, known as the portable engine, was not self-propelled but had to be towed to where it was needed by horses or a traction engine. It was used mainly for powering saw mills and electricity generation at fairgrounds. A semi-portable form, although without wheels, consisting of a boiler with the engine mounted on it, found favour in saw mills as well as flour mills and in small, often rurally situated, factories, where a cheaply run engine of moderate hp was needed. A variation, known as the undertype, had the engine placed beneath the boiler in the same position as the cylinders of a railway locomotive. Rarely did these portable types of engine exceed 150 hp.

The patenting of a practical steam turbine in 1884 by C. A. Parsons (1854-1931) was one of the most significant events in the evolution of heat engines as prime movers, and marked the beginning of the end for the reciprocating steam engine. It also brought to fruition the dreams of scientists and engineers over many centuries who had been fascinated with this problem of rotary power. Between 1784 and 1884 nearly 200 patents were taken out in Britain alone for steam and gas turbines, some of them anticipating in principle designs which were ultimately to be successful. In the turbine the steam, instead of being used under pressure against a piston, is set in motion, and the conversion of this pressure energy into velocity or kinetic energy produces the rotation of the turbine shaft. Parsons\* success lay in his appreciation of the problem of expanding the steam effectively through the turbine, a problem which he solved by dividing the pressure drop into many small stages, at each of which was an elemental turbine. Each of these turbines consisted of a ring of blades mounted on a long shaft, the rotor and the stator, which carried similar rows of blades projecting inwards between the rows of blades on the shaft. Steam admitted at one end of the stator flowed

\* Parsons issued instructions that the apostrophe should be omitted in cases like this, preferring to offend those who knew than suffer those who did not.

parallel to the axis of the turbine, that is axially, between the blades of the rotor and stator alternately, eventually exhausting to atmosphere. In order to eliminate end thrust on the rotor bearings Parsons arranged a central admission point for the steam, whence it flowed through two identical sets of blades towards each end of the turbine.

The incentive behind the development of the steam turbine, like that behind the high speed reciprocating engine, was the need for an effective power source for electricity generation, and in this role it proved an immediate success. Indeed Parsons first turbine was direct-coupled to a 7.51 kW dynamo using steam at 80 lb per sq in and running at a speed of 18,000 rpm. The rate at which improvements were made by the original inventor was remarkable, and by 1900 1,250 kW units were in service, rivalling in power output and efficiency the best reciprocating engine generators. In 1897 the first practical marine application of the turbine was made by Parsons in the experimental *Turbinia* fitted with three axial flow turbines direct-coupled to three screw propellers. Steam from the boiler was led first to the high-pressure turbine on the starboard side, then passed to the intermediate pressure turbine on the port side and next to a low pressure turbine placed amidships before being exhausted to the condenser. A separate turbine on the central shaft drove the vessel astern. The spectacular introduction of the marine turbine to the assembled navies of the world at the 1897 Spithead review, when *Turbinia* raced up and down between the ranks of ships at an unprecedented 34.5 knots, established beyond all doubt its supremacy over the reciprocating engine. Exactly 10 years later the Cunard liner *Mauretania* of 38,000 tons attained 26.04 knots powered by steam turbines of 70,000 hp.

Two important Parsons turbine generating units are preserved in the Science Museum, South Kensington. These are his original 1884 unit with bipolar dynamo and the first condensing turbo-alternator of 100 kW built for the Cambridge Electric Lighting Company. Other Parsons turbines may be seen at Abbeydale industrial hamlet, Sheffield; Glasgow Art Gallery & Museum, Kelvingrove; and, appropriately, Newcastle-upon-Tyne Museum of Science & Engineering, where *Turbinia* is also preserved. Also at Glasgow Museum are an early De Laval turbo-generator and a high pressure and low pressure turbine from the Clyde steamer *King Edward* of 1901, the first commercial turbine-driven vessel in the world.

The steam engine, as we have seen, was the first effective power source to release man from his reliance on natural agencies—on his own muscles, the use of animals or on windmills and watermills. Power was available in almost unlimited quantities for the driving of machines and the early application of steam to transport in the form of ships and railways means that this one prime mover occupies a fundamental position in the expansion of industry and the development of industrial society in the last 250 years. Over this period the reciprocating steam engine has come to command a respect quite unique among machines, from a wide range of people who gain some aesthetic satisfaction from the sight, sound and smell of a steam engine in action. Today the industrial archaeologist, in tracing the evolution of the steam engine, can find numerous examples preserved which illustrate many of the major stages of development, although beam engines of one type or another are by far the most numerous. So far very few of the last generation of large steam engines have been kept and, although a number of mill engines, colliery winding and pumping engines are still in regular use, their numbers are decreasing rapidly. The Dee Mill engine at Rochdale is the exception which proves the rule but as yet no example of the big triple-expansion vertical pumping engines built in large numbers down to the 1920s has been scheduled for preservation. Similarly the steam turbine, much less interesting visually, does not have a wide enthusiast following, and only a few small and early examples have been preserved, as static exhibits in museums.

#### THE INTERNAL COMBUSTION ENGINE

The significant history of the internal combustion engine lies mainly in the period between the 1850s and the present day, although the experimental beginnings go back much further. Indeed the concept of burning fuel in the working cylinder is older than that of the steam engine itself, being ascribed to the Dutch scientist Christiaan Huygens (1629-95) who devised a machine using burning gunpowder to provide the expansive forces necessary to raise a piston. Cooling of the gases created a partial vacuum and atmospheric pressure forced the piston down. It was the substitution of gunpowder by steam, using an external fuel source, that was to lead to the development of a practicable engine in the early eighteenth century.

It was not until 1859 that an engine burning its fuel within the cylinder was devised to operate continuously under industrial conditions, but by then the steam engine was universally established and in an almost unassailable position. Earlier experimental machines had been built and an engine made in 1820 by the Rev W. Cecil of Cambridge using hydrogen as a fuel was perhaps the first internal combustion engine to work in Britain or, for that matter, in the world. Nothing came of it, however, nor of the dozens of patents for 'gas exploding' engines taken out in the first half of the nineteenth century.

Success was finally achieved by a Frenchman, Etienne Lenoir (1822-1900), who in 1859 introduced a gas engine resembling in appearance a double-acting horizontal steam engine. A gas and air mixture was admitted at each end of the cylinder alternately but there was no compression. The mixture was introduced during the early part of each stroke, then fired by an electric spark and expanded during the remainder of the stroke. There were thus two explosions, one on each side of the piston, per revolution of the crank. While induction, ignition and expansion were taking place on one side of the piston, burnt gas was being exhausted at the other. Although small, ranging between  $\frac{1}{2}$  and 3 hp, and consuming rather large quantities of gas, Lenoir's engine achieved a considerable measure of success, 300-400 being in use in France by the mid-1860s. An example can be seen in the Science Museum, South Kensington.

In 1862 another Frenchman, Alphonse Beau de Rochas (1815-91), obtained a patent for a gas engine employing what we now call the four-stroke cycle. He laid down a range of conditions for good efficiency, namely: the cylinder should have the greatest possible volume with the least possible cooling surface, there should be the greatest possible rapidity of expansion and ratio of expansion, and the greatest possible pressure in the cylinder at the beginning of expansion. These conditions led to the following sequence of events in his engine:

- 1 Suction or induction of the gas-air mixture during a complete outward stroke of the piston.
- 2 Compression during the following inward stroke.
- 3 Ignition at or near the dead point followed by combustion and expansion during the third stroke.

- 4 Exhausting of the burnt gases from the cylinder on the fourth and final inward stroke.

The cycle is then repeated. Beau de Rochas did not follow up his theory and it was left to a German engineer, Dr N. A. Otto (1832-91), to put it into practical operation.

During the 1860s Otto had developed an 'atmospheric' free piston gas engine bearing striking resemblances in its principles of operation to the Newcomen steam engines of a century and a half earlier. The piston, mounted in an open-topped vertical cylinder, was raised by the expansion of gases ignited beneath it. Cooling and contraction of these gases resulted in the atmospheric pressure on top of the piston forcing it down. This was the working stroke, and a toothed rod, or 'rack', attached to the piston engaged in a gear wheel on a shaft converted its motion into rotary power suitable for driving machinery. Fuel consumption was substantially less than in Lenoir's engine and, after its introduction by the firm of Otto & Langen in 1867, it had soon driven almost all competitors off the market. In Britain Crossley Bros Ltd of Manchester produced the engine under licence in a variety of sizes and a number have been preserved in museums. Examples of the 2 hp type may be seen at South Kensington and Glasgow Art Gallery & Museum, while Bristol City Museum has a 4 hp version in store.

By 1876 Otto had produced a still more successful engine operating on the four-stroke cycle proposed by Beau de Rochas. The 'Otto Silent Engine' without doubt marked a milestone in the progress of the internal combustion engine, being the first really strong competitor to the steam engine and, in proving the practicability of the four-stroke cycle, forming the basis for the motor car engine of today. Crossley's took up this new Otto engine and produced a variety of sizes under licence. Large numbers have found their way into museums, as have similar slow-speed single-cylinder horizontal gas engines made by other British manufacturers. A number of types and sizes may be seen in the Birmingham Museum of Science & Industry, where a Tangye engine is usually running on gas.

In all these early four-stroke gas engines steam engine practice was followed to a large extent. They were usually slow-speed horizontals with admission of gas and air controlled by a slide valve. Although some engines used electric ignition, others relied upon a continuously burning flame inside a chamber

in the cylinder wall. When the firing point arrived, the slide valve opened a slot exposing the flame to the mixture in the cylinder. Ignition of the gases, however, extinguished the flame itself so it was necessary to have a second one outside the chamber in order to re-ignite the internal flame. At the moment of ignition the external flame was shut off from the internal one. A later idea was the hot tube kept at bright red heat by an external flame.

The fuel used in most of the early gas engines was town gas, but gas from coke ovens, blast furnace gas and producer gas were also employed. By the end of the nineteenth century special gas producers, using coal, were being made for direct coupling to gas engines, thus making them independent of piped gas. In most designs the main piston of the engine was used to draw air into the producer. In the 1870s a number of engineers, notably in Austria and the United States, were experimenting with engines using an oil fuel instead of gas but little success resulted, largely because of difficulties in getting the oil into a sufficiently divided or atomised state to be easily combustible. The first really satisfactory design was the Priestman engine of 1886, which used paraffin (kerosene) as its fuel. The liquid was atomised by compressed air and vaporised in a vessel heated by exhaust gas before being drawn into the cylinder with the fresh air charge and ignited by electric spark. The Hornsby horizontal oil engine had a vaporiser at the end of the combustion chamber, on the cylinder head, and a special portable oil lamp was used to preheat it before starting, while in Crossley engines vaporisation was achieved in a spiral pipe encircling the oil lamp chimney. Once the engine was started and reached its operating temperature, the lamp was no longer required. All these early oil engines were slow-running single-cylinder water-cooled horizontals similar in general arrangement to both gas and steam engines of the period.

About 1890 a very different type of oil engine was designed by Herbert Ackroyd-Stuart (1864-1927), who owned an iron foundry at Bletchley where he conducted experiments with the advice of Prof William Robinson of University College, Nottingham. The engine had a combined vaporiser and explosion chamber forming part of the cylinder head. The vaporiser, which was in the shape of an elongated bulb, was maintained by the heat of combustion at a temperature high enough to vaporise the oil which was injected directly into it, and high enough to cause ignition of the fuel/air

mixture at the end of compression. For starting purposes the vaporiser was heated with a blow lamp.

The Ackroyd-Stuart engine exhibited two features of great importance. It required no devices for igniting the inflammable mixture, once it had started, and the fuel was injected 'solid', that is, without the use of atomising air. These two features are characteristic of the modern high-speed oil engine, but it must be emphasised that the modern engine is fundamentally one of high compression, whereas the Ackroyd-Stuart design deliberately avoided high compression and provided auxiliary means for reaching the necessary ignition temperature. Lack of capital prevented Ackroyd-Stuart from carrying on his experiments and in 1891 he sold a licence to manufacture his engines to Ruston & Co of Lincoln, who made them successfully for a number of years.

Rudolph Diesel (1858-1913), a German engineer born in Paris, was responsible for taking the final step of developing an engine in which ignition took place solely by the heat generated by compression. His principal aims were to circumvent the two main sources of heat loss in an internal combustion engine—by controlling the maximum temperature, through the gradual introduction of the fuel, and by lowering the temperature of the exhaust gases. To these ends he designed an engine working on the four-stroke cycle in which pure air only was compressed by the piston to a very much higher degree than the mixture in any former type of oil engine. An injector pump then forced a minute but accurately determined quantity of oil into the combustion chamber, where it ignited spontaneously on contact with the compressed air. It was found that its maximum thermal efficiency was some 11 per cent higher than that of any other form of prime mover and that the engine worked well on a wide variety of petroleum oils. Initial disadvantages resulted from high weight, as the engine had to be solidly built to withstand pressures of up to thirty-five times atmospheric, but improved construction techniques had, by the 1920s, put the Diesel engine into a strong competitive position for both stationary and automotive uses.

It was Gottlieb Daimler (1834-1900) of Württemberg who successfully developed the small lightweight high-speed engine running on liquid fuel, in this case light petroleum spirit. In 1885 he patented a single-cylinder vertical engine with enclosed crankcase and flywheels. From this design all

subsequent Daimler engines were derived and in two- and eventually four-cylinder versions this type of engine formed the basis for the evolution of the motor car. A suction-operated inlet valve was used with a mechanically worked exhaust valve, a governor being arranged to prevent the latter opening when engine revolutions exceeded a predetermined speed. Introduction of the fuel was not such a difficulty as with the oil engine, as petrol vaporises readily in the presence of air. Wick feed carburettors were soon to give way to jet feed types, particularly for road vehicles.

Almost exactly contemporary with Daimler's introduction of the high-speed engine in 1885, Karl Benz (1844-1929) was building his first motor vehicle. This incorporated a horizontal engine using petrol as a fuel and operating on the 'Otto' four-stroke cycle but at the slow speeds of a gas engine. It was the high-speed engine pioneered by Daimler which eventually triumphed, however, and although a number of ingenious variations and layouts were tried in the period before World War 1, the general arrangement of vertical water-cooled cylinders and enclosed crankcase is still by far the most popular type of motor car engine throughout the world. Numerous early motor cars are preserved in museums and often their engines can be examined closely. Notable collections include those of the National Motor Museum at Beaulieu in Hampshire; the Science Museum, South Kensington; the Herbert Art Gallery & Museum, Coventry; and Glasgow Transport Museum. For a real appreciation of the early motor car engine in operation, however, the London to Brighton road on the first Sunday in November, the occasion of the Veteran Car Club Run, enables one to see, hear and smell the faltering post-natal beginnings of the machine which has had such a fundamental effect on the lives of us all. The Historic Commercial Vehicle Club run takes place over the same route on the first Sunday in May.

Despite the fact that the internal combustion engine is so familiar, and indeed commonplace, in the everyday world, its origins and early years are as much the province of industrial archaeological enquiry as are those of the steam engine. The rate of development of internal combustion engines has been such that almost any example dating from before 1930 and still in use is a rarity. Paradoxically it is often the Otto-Crossley gas engine of the 1880s, slow-running and slow to wear out, which has survived to be preserved.

## 5 Coal

THE earliest miners were interested in flint, from which they made their tools, and to reach the best layers in the flint-bearing chalk, they excavated simple pits. These first mines, probably excavated by Mesolithic or Middle Stone Age Man of perhaps 10,000 years ago, were little more than simple holes in the ground; but by the Neolithic period, which ended about 2000 BC, much more sophisticated mines were being dug, with galleries extending from shafts to the flint-bearing levels. The flint mines of Europe were on or near the chalk outcrops in northern France, Belgium and southern England. In Norfolk the most extensive mining site, which is known as Grimes Graves, covers some 34 acres, but smaller remains survive at Cissbury in Sussex, Worthing and Chichester.

The succeeding Bronze Age saw the working of lead, tin and copper, and finally iron, which displaced the tin-copper alloy bronze as a toolmaking material. Coal too may have been worked at places where it outcropped and even possibly in small pits of shallow depth. It was of some small importance to the Romans in Britain but the Saxons and Danes appear to have disregarded coal almost entirely, using wood and peat to heat their dwellings. No mention of coal occurs in the Domesday survey of 1086, but by the time of Magna Carta in 1215 the industry had certainly started on the banks of the Rivers Tyne and Wear and the Firth of Forth, where coal was gathered from outcrops and occasionally mined.

Coal did not become a really important fuel until the sixteenth century, and in terms of industrial development it was not of major significance until the middle of the eighteenth. From then on, however, coal was far and away the most important of all the natural resources of Britain, providing heat for both the smelting and fashioning of metals and the generation of steam. Initially coal was not a popular fuel and for domestic use wood and charcoal were generally preferred. Only poor people living near the workings burnt coal. The impurities in coal which caused the noxious fumes so distasteful to the domestic user in a house with inadequate ventilation also caused problems to industry, so it was in a purified state, as coke, that coal was first used on a really large scale for industrial purposes. Thus coke was

the first successful replacement of charcoal for iron smelting in 1709. Similarly, it was not until 1859 that the introduction of the brick arch into the fireboxes of railway locomotives enabled coal to be burnt satisfactorily. Previously coke had been used in all except small and relatively inefficient engines working in or near collieries.

This does not mean that coal had no industrial uses. Limeburners, bakers, brewers and glassmakers, for example, all adapted their processes to burn coal and, as the huge forested areas of England became decimated, the price of timber, coupled with the strategic timber requirements of the Royal Navy, stimulated an increase in the use of coal wherever possible. By the 1760s the coal industry was growing at a rapid rate, and it reached its peak in 1913; since then it has suffered a steady decline in the face of oil, and more recently natural gas and nuclear power. It is worth remembering, however, that most of the electricity generated in Britain comes from coal-fired power stations.

The first access to coal was at outcrops where it could be picked up on the ground, and on beaches where coal in cliffs was being constantly eroded. By the twelfth century small quarries and ditches were being dug, and in the thirteenth century, in addition to such opencast methods, coal was also being won from shallow drifts and bell-pits. Drifts were usually found in hilly districts and consisted of more or less horizontal tunnels or galleries cut into the hillsides and following the seams of coal. A number of privately owned drifts are still being worked under licence today, and although they are small by twentieth-century standards, they are much larger than their thirteenth-century predecessors. In areas such as the Forest of Dean in Gloucestershire there has been a continuous history of drift mining, and the 'free miners' of the Forest still exercise their medieval rights to mine coal (Plate 16). Their workings, although involving some modern equipment, are little altered from those of 5 centuries ago and include many of the basic techniques of mine operation. A reconstruction of a small drift mine can be seen at Blists Hill Open Air Museum, Ironbridge, Shropshire. Recently the National Coal Board has built a number of new large drift mines, notably in South Wales and Yorkshire.

Problems of ventilation and drainage limited the size of the early drift mines, but where coal lay at only a shallow depth below the surface, it was won by sinking bell-pits, a simple process involving little equipment



16 A free miner's working near Parkend, Forest of Dean, Gloucestershire

and no drainage or ventilation gear. Bell-pits are so called because, when viewed in section, they have the shape of bells. A pit was sunk like a well shaft to a shallow coal seam and the coal at the foot of the shaft was then taken. Next, it was cut away around the pit bottom in all directions until the sides were in danger of collapse. The pit was then abandoned and a new one started nearby. Bell-pits (Plate 17) were rarely more than 30ft deep, usually circular in plan, and often dug very close together. Very frequently they collapsed after their abandonment, so that areas of bell-pit working can now be recognised by a characteristic pock-marked surface to the ground made up of numerous circular depressions 20–30ft in diameter. Evidence of bell-pits can be found on many of the older worked coalfields, particularly in Derbyshire at Stretton, Wingerworth and Shipley, in Lancashire at Castercliff near Nelson, and in Shropshire on Brown Clee.

Where seams lay deeper than 20ft, bell-pits were wasteful of labour, so headings were cut out horizontally into coal for a short distance from the shaft bottom. Between these headings wide pillars of coal were left to support the roof. The arrangement was at first irregular in pattern, resulting in as much as half the coal being left behind, but it was soon recognised that it



17 Remains of bell-pits near Wakefield, Yorkshire

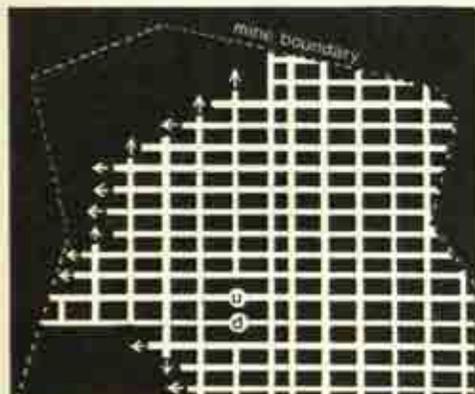
was both practicable and economical to divide the seams up into large pillars by roads driven at right-angles, and subsequently to follow up by extracting the pillars. This method of mining is known as bord-and-pillar or, more commonly, pillar-and-stall working (Fig 15). There were two distinct stages in the cutting of coal in this way. Initially, when the bords or stalls were being driven as working advanced from the pit bottom, the process was known as 'working in the whole'. The second stage, of extracting the pillars while retreating back towards the shaft was called 'working in the broken', although most miners would call this 'robbing the pillars on the retreat'. The method of removing pillars was to take slices off one side, the roof meanwhile being supported by timber props. When the whole of the pillar was cut away, the timber supports were withdrawn and the roof allowed to collapse.

Pillar-and-stall working became the standard method of coal extraction in all the major coalfields of Britain, and in Northumberland and Durham in particular continued well after nationalisation of the coal industry in 1947. The miner of the North-East, with his highly developed tradition of craftsmanship and skill, tended to be rather slow in adopting new mining techniques. The system of working, in which an individual miner or small group of men worked a stall also engendered a craft approach and perpetuated

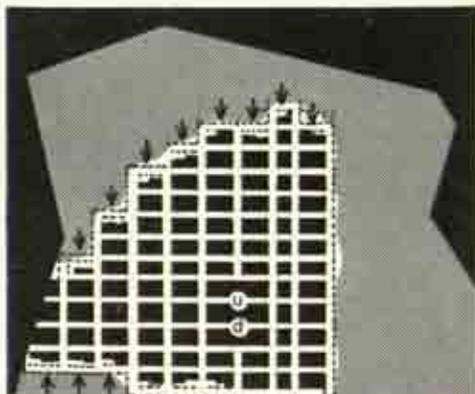
# METHODS OF WORKING COAL PLAN VIEW OF COAL SEAM

## PILLAR-AND-STALL

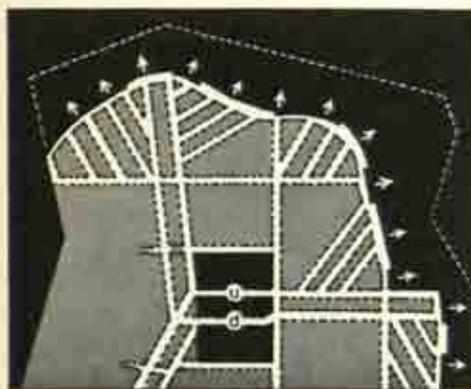
1 Working in the whole



2 Working in the broken



## LONGWALL



-  uncut coal
-  coal removed, roof still supported
-  'goaf' or 'gob'- all coal removed, roof allowed to settle down gradually
-  workings kept open with props
-  upcast shaft - foul air drawn out
-  downcast shaft - fresh air drawn in

NB Circulation of fresh air round the mine is controlled by air doors and ducts which have been omitted for clarity

Fig 15

this system of mining long after it had been replaced elsewhere by other techniques.

Pillar-and-stall working was a two-stage operation ideally suited to workings where there was not more than about 900ft of rock lying above the coal. Where depths were greater, there was a tendency for the overlying rock to crush the pillars as, or sometimes before, they were removed. There were also frequent problems of ventilation. To overcome these drawbacks, extraction in one operation was developed. Known as the longwall method, it originated in the late seventeenth century, probably in Shropshire, but did not come into widespread use until after 1850. In this system a wall of coal about 100yd long is won out and removed bodily in line. As the coal is taken away, any stone available is built into dry stone walls or packs 6-20ft wide arranged in parallel lines at right-angles to the advancing wall or face. The purpose of these walls is to support the roof after the layer of coal is removed and thus preserve it in a largely unbroken state. Longwall working is particularly suited to mechanical coal-cutting methods in seams which have layers of stone or shale within them.

Once mines had grown beyond the scale of the early drifts and bell-pits, the cutting of the coal itself became a relatively minor problem compared with those of shaft sinking and winding, ventilation and drainage. Indeed the finding of a solution to these last two difficulties was the major pre-occupation of miners and engineers from the end of the sixteenth century onwards. Until answers could be found, there were specific limits to the depth at which mines could be sunk and the distances to which workings extended from the pit bottom. The early miners on the exposed coalfields were working in known conditions. They could see where the coal was and assess the problems of working as they went along. Once mines away from the outcrops developed, shaft sinking became speculative and some means of discovering the presence of coal and any undesirable stratigraphical conditions above it became a necessity. As early as 1606 Huntington Beaumont, one of the first of the great coal entrepreneurs, who had extensive interests in Nottinghamshire and the North East, was demonstrating his 'art to boore with iron rodde to try the deepnesse and thickness of the cole'. This of course was much cheaper than digging trial shafts. In 1708 the cost of boring was said to be 15-20s a fathom, while sinking a shaft cost 50-60s a fathom. In 1804 James Ryan invented a boring technique which allowed

cores to be extracted, and the application of steam power, first tried by Richard Trevithick, both speeded up and cheapened exploration.

Shaft sinking was usually carried out by hand picks and shovels and wedges for splitting rock. Later boring rods were employed, and in 1749 occurs one of the earliest references to the use of explosives, for a 210ft shaft near Halifax. Shafts were generally circular in section, 5-12ft in diameter, with about 7ft being the most common, though one shaft at New Rock Colliery, Somerset (166/ST 647505), in use until recently, is only 4ft 6in in diameter. Square or rectangular shafts were frequent on some coalfields as they could be easily and cheaply lined with wooden boards. Small rectangular shafts can still be found in the Forest of Dean, although often the timber lining has deteriorated, making them very dangerous to explore. Where water was a problem in a shaft, it was held back with 'tubbing' consisting of wooden planks arranged like the staves of a barrel or tub. The first cast-iron tubbing used in the Midlands was at Snibston Colliery in Leicestershire (121/SK 417145), sunk by George Stephenson in 1841-3. This can still be seen in the upcast shafts. Elsewhere brick lining was used, mostly with mortar but occasionally without. It was cheaper to lay bricks dry, and they could be used again when the shaft ceased production. A dry-lined shaft can be seen below the headgear from Farm Pit, Heath Hill, reconstructed at Blists Hill Open Air Museum, Ironbridge (119/SJ 694031).

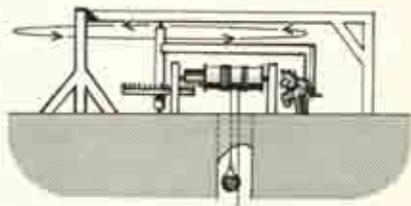
There were various methods of raising coal up the shaft (Fig 16), of which the earliest was a simple hand winch or windlass, sometimes known as a 'jack roll' and similar to that used on a domestic well. The barrel of a windlass of this type, found in 1969 at the bottom of a shaft exposed on Stainsby Hag opencast site in Derbyshire, may be seen in the Mining Museum at Lound Hall Mining Training Centre, near Retford, Nottinghamshire (112/SK 701731). To improve the performance of the hand windlass, horse-driven cog-and-rung gins were introduced in the early seventeenth century. A vertical spindle was geared to the horizontal barrel of the winch, and the horse, attached to the spindle via a wooden pole, walked round the mouth of the pit to raise coal in small baskets known as corves or corfes. Towards the end of the seventeenth century further improvements were effected with the whim-gin, horse-whim or whimsy. This new winder had the rope drum mounted on a vertical shaft, which was erected some distance from the pit shaft. The horse walked round rotating the drum as in the cog-

# COLLIERY WINDING GEAR

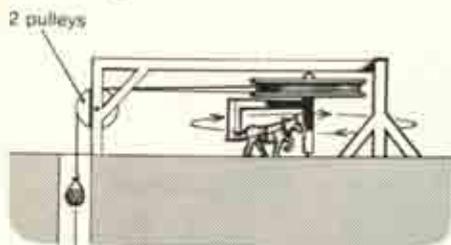
## Windlass or Jack Roll



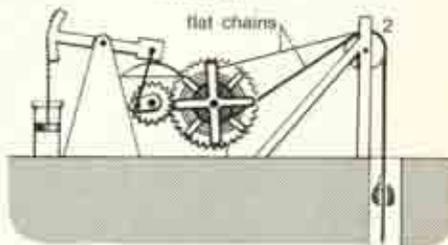
## Cog and rung gin



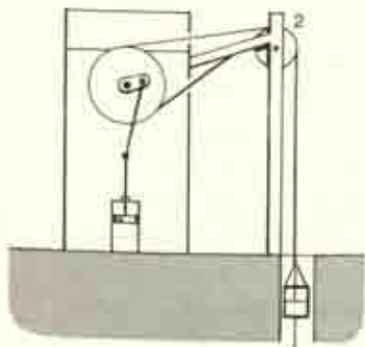
## Whim-gin



## Steam whimsy



## Vertical steam winder



## Horizontal steam winder with tandem headgear

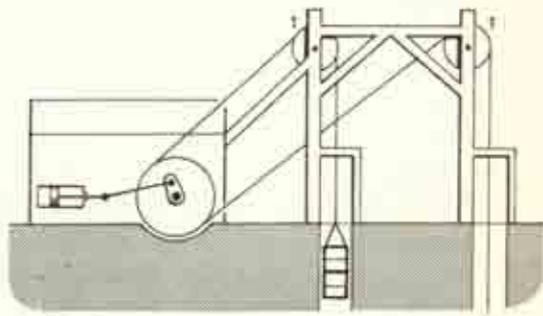


Fig 16

and-rung gin and the rope passed over a vertical pulley mounted on a wooden headgear over the shaft itself. Depending on the size of the mine, one, two or more horses were employed. Whim-gins were used until the early twentieth century in some places and a reconstructed example may be seen at the Nottingham Industrial Museum, Wollaton Park (112/SK 531393).

The use of water power for winding purposes occurred to a limited extent in Britain, initially with waterwheels mounted on horizontal shafts round which the winding rope was wound, and later using water balances. A waterwheel for winding coal was installed at Griff Colliery, Warwickshire, by John Smeaton (1724-92) in 1774, and in the North East non-rotative steam engines were used to raise water which was also used to power 'water gins'. No evidence survives of waterwheel winders but in South Wales, where water balances were used, a well preserved balance tower can be seen at Blaenavon (154/SO 250094). In a water balance coal was drawn up the shaft in a cage by the weight of a tub, filled with water at the pithead, which descended in a parallel shaft. When the water tub reached the bottom, the water was drawn off through a valve, a tram of coal was placed on top of the empty tub and then drawn up the shaft by the weight of another descending water-filled tub. An example from the Forest of Dean is displayed in the National Museum of Wales, Cardiff.

The earliest use for the steam engine, at the beginning of the eighteenth century, was for mine drainage, but it was not until 1784 that the first steam winder, a Watt engine, was erected, at Walker Colliery on Tyneside. The early steam winding engines were primitive and somewhat unreliable which encouraged the persistence of horse-gins at many small and poorly capitalised pits. One of the problems in tracing the introduction of steam winding in the late eighteenth century and early nineteenth results from the use of the word whimsy to describe a steam engine or a horse-gin, so that it is often difficult, if not impossible, to distinguish one from the other. What is certain, however, is that steam power was rapidly adopted, particularly in the large collieries of the Midlands and North East and that it remained the primary means of winding both coal and men until well after nationalisation in 1947. Electric power, introduced about 1906, has since 1947 become almost universal, and there are now thought to be less than twenty steam winders working in Britain, although a number of dead engines survive. Some have been preserved and others recorded on film.

18 Chimneys and pumping house, Jane Pit, Workington, Cumberland



Many of the early engines worked on the Newcomen atmospheric principle with open-top cylinders and timber beams, and by the end of the eighteenth century large numbers were being made, notably by the Coalbrookdale Company. A Newcomen-type winder used at Farmie Colliery, Rutherglen, Scotland, between 1810 and 1915 is preserved at Glasgow Museum but is not on display at the time of writing. It has a 42in diameter cylinder with a stroke of 5ft 8in. By the mid-nineteenth century a standard layout of winding engines had developed. It comprised a drum on a horizontal shaft at each end of which was a crank; two horizontal cylinders, usually mounted on separate cast-iron bedplates, which also supported the crankshaft bearings, drove this shaft. The engineman had a control platform

mounted above the cylinders, whence he could survey the whole engine-house and in many cases see the pithead too. Most engines that survive today are of this twin-cylinder horizontal type. Notable among these is the engine from Old Mills Colliery near Radstock in Somerset, built in 1861 by William Evans at Paulton Foundry and now preserved by Bristol City Museum. This engine, which is not on display, has cylinders of 26in bore and 5ft stroke, with a rope drum 12ft in diameter. A small horizontal engine with one cylinder and its crankshaft geared to the winding drum shaft instead of the more normal direct drive has been re-erected and is running on steam at the Blists Hill Open Air Museum, Ironbridge. The engine comes from Milburgh Pit near Broseley, Shropshire.

Of generally the same layout as twin-cylinder types is the large twin-tandem compound engine at Astley Green Colliery, Tyldesley, Lancashire (101/SJ 705999), built by Yates & Thom in 1908. In many ways it resembles a contemporary mill engine, with Corliss valve gear and a white tiled interior to the engine house. The engine is now out of use and may be scrapped, but there are hopes of preserving a twin-cylinder horizontal capstan engine once used in connection with maintenance of the shaft. The headstocks at Astley Green are typical of those built at larger collieries early this century, with four legs of lattice steel construction standing astride the top of the shaft.

A notable regional variation from the standard horizontal winding engine occurred in North East England, where vertical winding engines were common on the Northumberland and Durham coalfield. The direct-acting vertical engine with crankshaft mounted above the cylinder, patented in 1800 by Phineas Crowther of Newcastle-upon-Tyne, formed the basis for engines built by Thomas Murray and James Joicey for pit winders. One example, at Beamish Colliery (78/NZ 220537), is preserved by the North of England Open Air Museum. Built in 1855 by J. & G. Joicey of Newcastle-upon-Tyne, the engine occupies a tall stone-built engine-house (Plate 19), and the timber headstocks have two vertical legs astride the shaft and two almost horizontal members running back to be supported in the front of the engine-house. Other surviving vertical winders are at Elemore, County Durham (85/NZ 356456), and Old Glyn Pit near Pontypool (154/ST 265999), where there is also a beam engine of 1845 that was formerly used for pumping. Both the Pontypool engines were built by Neath Abbey Works.

The introduction of steam engines for winding resulted in new types of



19 Beamish Colliery, County Durham. Winding engine-house and headstock, 1855

winding rope being used. Those originally employed were round and made of hemp that consisted of several strands wrapped to form a composite rope. Flat ropes, in which the strands were stitched together side by side, were also extensively used, and had the advantage that during winding the rope could be wrapped layer upon layer on a narrow drum, thus varying the leverage. At the beginning of winding, with the load at the bottom of the shaft, the rope was wrapped around the smallest circumference of the drum and the empty basket or cage on its own rope at the top was wrapped round the largest. A similar form of continuously variable gearing can be seen on the winding drum at Astley Green Colliery, where a scroll on the side face of the drum feeds the cable from the small diameter at the beginning of the wind to the full diameter of the drum when the load is moving. In early coalmines, baskets or corves were wound up from the trams at the foot of the shaft on free-hanging hemp ropes, but owing to the twist on the rope they tended to spin round and sway from side to side. Thus the speed of winding had to be slow. To overcome this swaying, shaft guides were introduced in 1787, and baskets were attached to cross-bars which slid in wooden guides attached to the sides of the shaft.



20 Cymcynon Colliery, Mountain Ash, Glamorgan. A typical late nineteenth-century headgear, now demolished

The introduction of stranded iron wire ropes after about 1840 led to their being widely adopted for winding and also as shaft guides, two cables being hung down each side of the cage and stabilised by heavy weights in the shaft sump. In Shropshire particularly, with its local chain industry, flat wrought-iron chain was extensively used for winding purposes. Known as 'rattle chain', it was used in much the same way as flat hemp or wire rope, and wound on to a narrow drum. Despite the fact that wear in chain was difficult to detect and breakages were sudden and unexpected, rattle chain continued in use throughout the nineteenth century. Lengths can still be found all over the East Shropshire coalfield, used for a wide variety of purposes, including fencing.

In the late 1840s cages were introduced to replace corves for lifting coal up the shafts, and by 1860 most collieries of any size had them. Even so, corves were used as late as 1875 at William Pit, Whitehaven. An example

is preserved at Lound Hall Mining Museum. The introduction of the cage, which was basically an open-sided box running on guides in the shaft, brought about the end of the primitive and dangerous methods of man-riding practised in many collieries. Often colliers merely clung to the rope to get up or down the shaft. Occasionally 'man engines' were used instead. The cage improved the efficiency of coal winding in mines greatly, as a load of coal could travel on rails in a truck or tram from where it had been cut at the coalface to the bottom of the shaft, run on to rails in the floor of the cage, be safely hauled to the surface and there be emptied while the cage returned underground with an empty truck. A typical small cage can be seen on the preserved Heath Hill Pit at Blists Hill Open Air Museum.

Having considered methods of mine operation, we must examine the two major problems facing the coalminer from the sixteenth century onwards—drainage and ventilation. The hand windlasses and horse-gins used for raising coal could also lift water, but there were obvious limitations to their capacity. By the end of the seventeenth century the size of coalmines and, for example, tin mines in Cornwall, was limited by the ability to keep them drained although in some collieries and lead mines quite effective use was made of underground ditches or drainage tunnels known in the North East as 'water gates', in the south as 'adits' and in parts of the Midlands, such as Derbyshire, as 'soughs'. These were clearly of little use for deep mines, and although wind and water power were used, it was the introduction of the steam engine after about 1712 that broke the deadlock. The steam engine was developed specifically for mine drainage and for the first half century or so of its existence did little else. The details of its development are considered in Chapter 4, as are some of the surviving examples which were used for mine drainage. These include the Hawkesbury engine now preserved at Dartmouth (188/SX 879513), which was originally installed in the 1720s at Griff Colliery, Warwickshire, and is the oldest steam engine in existence, and the atmospheric drainage engine at Elsecar (102/SE 390003) in the West Riding of Yorkshire. The Elsecar engine is preserved on its original site by the National Coal Board. Adjacent to the engine house is a timber headstock over a small shaft. Another atmospheric engine, of 1791, was acquired in 1917 from Pentrich Colliery, Derbyshire, by the Science Museum, where it is now preserved.

One of the most spectacular colliery sites and drainage engines is at

Prestongrange, East Lothian (62/NT 374737), on the B1348 road east of Musselburgh. At the centre of the site is the Cornish beam pumping engine by Harvey's of Hayle, Cornwall, which pumped water from the mine from 1874 to 1954. The beam weighs approximately 30 tons, is 33ft long and 6ft 4in deep at the centre. The single cylinder is 70in in diameter with a stroke of 12ft. The engine and its surroundings form the basis for a preservation scheme sponsored by East Lothian County Council with the assistance of the National Coal Board and various local organisations. It is intended to collect equipment and documentary material illustrating the history of coalmining in Scotland and display it in the recently restored colliery power house. Elsewhere it is difficult to find surface evidence of colliery drainage works, although here and there an engine-house survives. The massive house of Calcutta Colliery pumping engine near Thringstone, Leicestershire (121/SK 424183), is one example, and another, of rather Cornish appearance, may be seen at Nailsea in Somerset (165/ST 479691). In some coalfields engines were installed away from the collieries themselves to drain whole areas in which the various mine workings were connected by levels. An example was the scheme to drain the Fitzwilliam Barnsley Bed in South Yorkshire, of which the Elsecar engine was part. Similarly the Lloyds engine, Madeley Wood, near Ironbridge (119/SJ 690031), of which recognisable remains survive, drained a number of mines in the area.

Before turning to mine ventilation, we should mention an unusual form of coal extraction at Worsley in South Lancashire, which combined drainage levels and soughs with the mine workings themselves. The site has considerable historical significance in the early development of canals and is readily accessible to the visitor. The entrance to the Worsley Mine (Plate 21) is north of Worsley Road and west of the Delph (101/SD 748005). For further details of these extensive workings, see p344.

As mines grew in size, problems of ventilating them increased. In small workings the only gas with which the miner had to contend was 'stytch' or 'dampe', known now as blackdamp or chokedamp. It is a mixture of carbon dioxide and nitrogen which in large quantities will suffocate all coming into contact with it. Later, as mines became deeper, firedamp, a mixture of methane and air, was encountered and the era of the serious mine explosions began. Another explosive element in mines—the concentration of fine coaldust—was not known about until much later. Firedamp is produced



21 Entrance to the coalmines at Worsley, Lancashire. On the left is a 'starvationer' boat used on the underground canal system

during the decay of vegetable matter and its conversion into coal; it remains in the cleavage planes of the coal and the nearby rocks and is released as soon as the seam is worked. In mixture with air at concentrations of 5–15 per cent methane it is highly inflammable. By the late eighteenth century colliery explosions, often of great violence, were common, especially in Northumberland, Durham and South Wales. There were 643 explosions in the North East between 1835 and 1850, even after the introduction and widespread use of the safety lamp devised by Humphry (later Sir Humphry) Davy (1778–1829) in 1815.

The Society for Preventing Accidents in Coal Mines, formed in Sunderland in 1813, largely as a result of the Felling colliery disaster of the previous year in which ninety-two men and boys died, approached Davy, who expressed interest in the problem. He discovered the true nature of firedamp, the conditions under which it explodes and the rate of passage of flame through tubes of varying diameter. He found wire gauze in the form of a sleeve around the flame to be the most effective barrier. The gauze was made from iron wire ranging from  $\frac{1}{16}$  to  $\frac{1}{8}$  in in diameter containing twenty-eight wires to the inch, or 748 apertures to the square inch. Two other men, Dr W. R. Clanny (1776–1850) and George Stephenson (1781–1848), the

steam locomotive engineer, also devised safety lamps at about the same time. Miners' lamps are common in most industrial museums, but a particularly fine collection may be seen at Salford in the Science Museum in Buile Hill Park on Eccles Old Road. Another collection is maintained by the Protector Lamp and Lighting Company of Lansdowne Road, Morton, Eccles M30 9PH, which is accessible by appointment. Safety lamps reduced the incidence of explosions somewhat, but when they did occur in the bigger mines, the results were often catastrophic. In 1860 145 men died in the Risca Mine at Newport; in 1867 178 lives were lost at Ferndale Colliery in the Rhondda Valley. The causes of these two have since proved to be the ignition of coaldust, and today steps are taken to combat this by spreading stone dust in the mine workings.

Most early mines relied on convection currents or natural air flow through two shafts for their ventilation. With increased size a forced ventilation system became necessary, and in the mid-seventeenth century the first reference to the use of a fire basket occurs, at Cheadle in North Staffordshire. Fire baskets and later ventilation furnaces were usually underground at the foot of the 'upcast' shaft. The upward movement of air due to the chimney effect of hot gases induced a downward flow in the 'downcast' shaft and the fresh air, circulated throughout the workings and controlled by trapdoors operated by boys, prevented dangerous concentrations of gas accumulating. A reconstruction of a surface ventilation fire and chimney may be seen at Blists Hill Open Air Museum, Ironbridge, and Brinsley Colliery, Nottinghamshire, still has the flues and furnace underground, though they have not been used since the nineteenth century. In Lancashire ventilation chimneys for underground furnaces could recently be seen at Clifton Colliery, Burnley, and Pewfall Colliery, Garswood. A surface ventilation furnace and chimney can still be seen at a drift mine at Trehafod in South Wales (154/ST 036910). The last recorded use of a fire basket was at Rock Pit, Shropshire, in 1965, and a surface furnace was used at Broseley Deep Pit, nearby, until 1941.

These survivals were anachronisms, however, and various types of air pump were being installed at the larger collieries from the 1830s onwards. One of the most widely adopted in the 1870s was the Waddle fan, a centrifugal fan of up to 45ft in diameter powered by steam or later electricity at the relatively low speed of 70 rpm. The fan consisted of two parallel discs

separated by backward curved blades. The centre of the disc was hollow and connected by a large-diameter pipe to the top of the upcast shaft. As the fan rotated, air was sucked in at the centre and expelled along the periphery. Between 1871 and 1896 220 Waddle fans were installed and a few still remain, though not now working. One was at Annesley, Nottinghamshire until recently, and another, from Ryhope Colliery, County Durham is preserved in the North of England Open Air Museum at Beamish. A Waddle fan at Abergorki Pit, Mountain Ash, Glamorgan (T54/ST 050990), is also to be preserved.

Before mechanisation began in the latter part of the nineteenth century, and in many collieries years after then, the miner relied on pick, shovel and crowbar to get the coal. By about 1800 explosives were being used in shot-holes made with a chisel-ended iron bar, or, later in the century, by a hand drill. Loose gunpowder was poured into the hole and tamped with clay, using a tamping bar. A pricker or needle left in the hole when the clay was tamped in would then be withdrawn to allow a straw full of priming powder to be inserted. This was lit and burned for long enough to give the shot-lighter time to retire. A slow-burning fuse was invented by William Bickford in 1831 but many miners would not use it on grounds of expense.

A good selection of miners' tools is preserved in the North of England Open Air Museum, Beamish, which also has crickets or working stools and various types of protective headgear. Below ground mechanisation came slowly, and the steam engine, so valuable for pumping or winding, was out of the question as a source of power for coal-cutting machinery. The use of machinery in mines grew with the development of compressed air and electricity, particularly the latter, as sources of motive power. A compressed-air-powered coal cutter, using a toothed disc, was introduced in 1863 by Thomas Harrison, and established the principle of the rotary or continuously moving cutter which applied until relatively recently. Three major types of cutting machines emerged, the first using a disc with teeth on its periphery, the second a continuous chain carrying cutters, similar to the chain saw used today for tree felling, and the third a rotating bar armed with cutters throughout its length. A variety of cutter-loaders have been tried in this century. The Meco-Moore was a widely adopted type, but it is now probably extinct; it travelled along the face cutting coal with two horizontal gibs, collected it and transferred it to a conveyor running parallel to the

direction of the traverse.

The rate of change of technology in the coal industry, as in many others, makes the work of the industrial archaeologist difficult, particularly as much of the machinery is not easily accessible, and cannot easily be preserved *in situ*. Museums such as the one set up at Lound Hall near Retford in Nottinghamshire are to be welcomed, therefore, as a means of fostering interest within the industry itself. Another museum in which there is some National Coal Board interest is the Science Museum at Bule Hill Park, Salford, where a 'coalmine' constructed in the cellars of the museum includes a variety of equipment from various periods. Modern coal-cutting machinery is also exhibited and there is a lamp room with miners' electric lamps on charge ready for the visitor to use. The Department of Industry of the National Museum of Wales, Cardiff, also has a substantial coalmining section and is involved in on-site preservation in the South Wales coalfield (see Appendix 1). A Siskol percussive coal cutter, c1913, from Rock Pit, Ketley, Shropshire, is preserved at the Blists Hill Open Air Museum. It was recovered from the workings by the Shropshire Mining Club, a specialist organisation and the only one of its kind in Britain carrying out systematic exploration and archaeological survey work underground in the Coal Measures.

No study of the industrial archaeology of the coal industry would be complete without mention of the transport systems which developed to service it. Detailed consideration of canals and railways is given in other chapters, but it is worth remembering that the exploitation of coal was fundamental to the evolution of both. Canals in the Midlands and South Lancashire, for example, developed as a means of opening up coalfields. Associated with the canal were horse-drawn tramway systems connecting individual pitheads with canal basins. In the North East and South Wales tramways or plateways networked the coalfields, encouraged by the generally favourable gradient downhill from colliery to river or coastal wharf. Late in the nineteenth century railway companies such as the Bowes Railway in County Durham, the Hull & Barnsley in Yorkshire and, for example, the Taff Vale, Rhymney, Barry and Cardiff railways in South Wales, were built primarily to carry coal. As many as four separate railway companies occupied some valleys in South Wales in their anxiety to share in the carriage of coal to ports such as Penarth, Cardiff or Barry. The most dramatic remnants of the coal trade are to be found in the North East where there

are still a few of the wharves, known as 'staithes', by means of which coal was shipped from wagon to vessel. The banks of the Tyne, later the Wear, and eventually such ports as Seaham Harbour, were the shipping points to which the wagonways led. The staithes originally served not only as gangways for loading, but also as storing places for the coal as mine owners found it desirable to keep a large part of their stock on the staithes, ready for immediate shipment, rather than at the pitheads, as shipmasters did not like delaying sailing while small wagon loads were brought from the colliery. The three distinctive features of the coal shipment industry were the staithes themselves, of which the best are at Seaham Harbour (85/NZ 435495), the chaldron wagons which ran on the wagonways and the coal drops which lowered the wagons over the holds of ships so that the coal could be discharged. A number of chaldron wagons and the last surviving coal drop, from Seaham, are preserved by the North of England Open Air Museum (Fig 17.). More modern staithes may be seen at Amble (71/NU 269049) and Blyth (78/NZ 3280).

The landscape changes wrought by the coal industry are of an infinitely broader scale than the effects of collieries and pit tips alone, and recognisable regional variations can still be seen. In South Wales the industry, crammed into the confines of narrow valleys, resulted in long straggling colliery villages of terrace houses, rarely more than three or four rows deep, strung out along the valley floors. Row upon row of Welsh slate roofs punctuated by tall nonconformist chapels lay among railway lines, many of which are now closed. In the North East the mining village was a new and distinct nucleated settlement generally fairly compact, well endowed with public houses but with perhaps fewer places of worship than in South Wales. Scotland and the Furness coast northwards to Whitehaven are noted for a preponderance of single-storey dwellings often rendered or pebble-dashed and invariably slate-roofed. The colliers of the Black Country or East Shropshire, however, where pits were often small, usually lived in semi-rural surroundings, their tile-roofed cottages scattered in little groups among smallholdings, overgrown waste tips and the dwellings of workers in other industries. Rarely is it possible to pick out the coalworker's house from that of the foundryman, iron puddler or chainmaker.

The North of England Open Air Museum has complete interiors from pitmen's cottages which can have changed little in half a century, but the

## COAL DROP AT SEAHAM HARBOUR, CO DURHAM

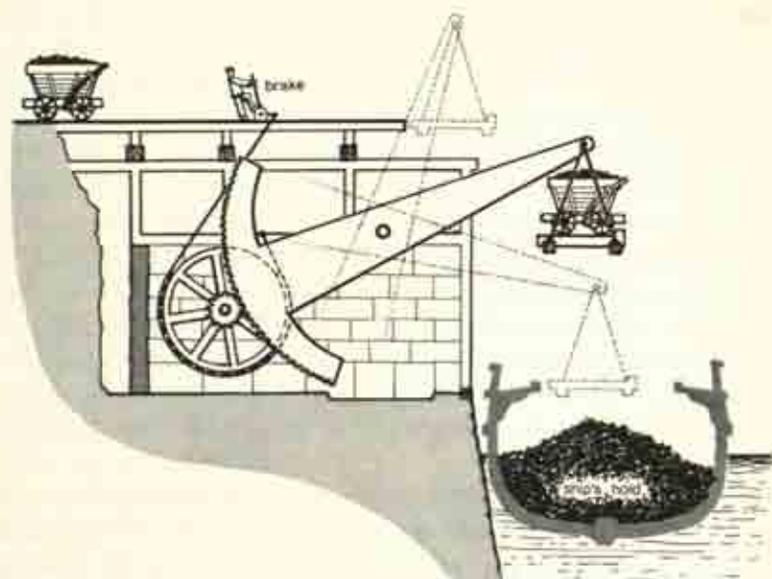


Fig 17

same cannot be said for other mining areas. Miners' clothing, both working and best, is almost unrecorded. Similarly, material evidence of the living and working conditions of the population of mining areas is surprisingly scarce.

The coal industry, in fact, provides the industrial archaeologist with an outstanding challenge.

## 6 Iron and Steel

IRON and its alloy steel are at the root of our material civilisation. Bridges, railways, ships, motor vehicles, tall buildings, machinery, tinned foods, and reinforced concrete are just a few aspects of our existence today in which iron and steel play a fundamental role. The evolution of techniques for making iron and later steel in quantity are therefore of overwhelming significance in the development of industrialisation. From the industrial archaeological point of view the remains of the iron and steel industry present certain problems. Many early sites are often only physically identifiable by the waste products left behind, and analysis of the slags and a detailed knowledge of the ironworking process is needed before one can gain any indication of what originally went on. The Historical Metallurgy Society is devoting itself to the early history, not only of ironmaking but of many non-ferrous metal processes also. The eighteenth century and the first part of the nineteenth, a period in which rapid advances in iron and steel making took place, provide rather more in the way of physical evidence readily open to interpretation, though remains from, say, the 1860s onwards, have been to a great extent obliterated by recent advances in the industry. In this respect the iron and steel industry is typical of a number where evidence of earlier processes is much more complete than that of later. Anyway, age is not necessarily of special significance in determining the relative importance of sites.

The three commercially important forms of iron, in order of antiquity, are wrought iron, cast iron and steel. Wrought iron, for nearly 2,000 years the only form of the metal which was used, is an almost pure iron, ductile and easily shaped in the hot state by hammering or rolling. It is fibrous, has a high tensile strength and a resistance to corrosion far superior to the modern mild steel which has replaced it. Small quantities of slag in the iron contribute to these properties and act as a flux in welding which can be done when the iron is heated to the right temperature, and hammered or squeezed. This process is known as fire welding.

Cast iron, containing a much higher proportion of carbon than wrought

iron (up to 3-4 per cent), is the product of melting iron to a completely liquid state and pouring it into moulds, where it solidifies. It has a crystalline structure, making it weak in tension but very strong in compression. It too is resistant to corrosion.

Steel has a wide variety of different forms but is basically an alloy of iron and carbon, but with less carbon than cast iron and more than wrought iron. Mild steel, the commonest form, contains not more than about 0.25 per cent carbon; it is ductile, strong in tension and can be forged, rolled and worked in much the same way as wrought iron. By varying the carbon content and subjecting it to heat treatment processes, steel can be hardened and tempered to give it additional strength and toughness. The addition of carbon to the outer surfaces produces a hard skin, a process known as case hardening. Today there are hundreds of different steels, each designed for a specific purpose and containing other elements such as manganese, nickel, chromium, molybdenum and tungsten. These alloy steels include high-speed steels, stainless steels and die steels.

Although iron is one of the most abundant elements in nature, it almost always occurs in association with oxygen in the form of iron oxides. There are two main types of commercially worked ores in Britain: stratified ores laid down on seabeds in the Carboniferous and Jurassic periods, and unstratified ore found as nodules. Carboniferous ores occur in association with the Coal Measures, and are the clayband and blackband ores found in the Lowlands of Scotland, South Yorkshire, Derbyshire, the West Midlands and South Wales. They are of medium quality with about 30 per cent iron content and formed the basis for the iron industry of the eighteenth and early nineteenth centuries. Today most of the easily accessible Coal Measure iron deposits are worked out. Jurassic ores occur in a broad band stretching from the Cleveland Hills in North Yorkshire through Lincolnshire, Leicestershire, Northamptonshire and Oxfordshire, where the most important quarries are today, to the Cotswolds. They are of low quality, with often as little as 20 per cent of iron content, but are particularly easy to extract. An isolated pocket of richer Jurassic ore in the Weald of Kent formed the centre of the medieval iron industry, and was important until the sixteenth century when working ceased. The most important unstratified iron ore is haematite, which occurs in the Carboniferous as purple nodules of high iron content (about 50 per cent) and has been worked in Cumberland, the Furness district of

Lancashire, Glamorgan and the Forest of Dean.

Evidence of iron ore extraction is very widespread, particularly in North Yorkshire, the East Midlands and the haematite areas of North West England. In the Cleveland Hills of the North Riding mining was the normal technique, beginning in 1836, reaching a peak output in 1883, and declining gradually after World War I to cease completely in 1964. The largest mine, at Eston (86/NZ 560186) was opened by Bolckow, Vaughan & Company in 1851 to work the Main Seam, and formed the basis for the initial growth of the iron and steel industry of Teesside. It closed in 1949. The Main Seam was also worked from 1872 at North Skelton (86/NZ 675184), the last mine to work in Cleveland and, at 720ft to the shaft bottom, the deepest. At Boulby (86/NZ 760181) the Skinningrove Company operated a drift mine from 1903 to 1934, erecting for their workers a shanty town of corrugated-iron houses which became known as 'The Tin City'. The remains of the foundations and floors are still visible. In Rosedale (92/SE 723946) magnetic ironstone from the Kitchings and Garbutts deposits was worked from the 1850s until 1885. Up to the opening of the Rosedale branch railway in 1861 nearly 40,000 tons of ore had been taken from these mines by packhorse to the railway at Pickering, the last large-scale use in Britain of this form of transport.

In the East Midlands the Jurassic ores are at relatively shallow depths and have generally been worked by opencast methods. The early workings, dating from the 1850s, were located close to the outcrops, but as these became worked out, steam shovels, introduced in the mid-1890s, had to be used to move the increased depth of overburden. By 1916 dragline excavators capable of stripping 25ft of overburden were being used, to be followed in 1933 by electrically operated shovels which could handle up to 55ft. In 1951 the first British walking dragline capable of removing 100ft of overburden was introduced. Initially, no attempt was made to reinstate the worked-over areas and evidence of the first large-scale workings can still be seen in the form of ridges and furrows, with an amplitude of up to 20ft, resulting from the dumping of the overburden after the ore had been removed. Today the quarry areas are levelled and the top soil replaced, leaving an open landscape of large fenced fields devoid of trees and hedges. A steam excavator is preserved in working order by the North of England Open Air Museum, Beamish, County Durham.

The technique of ironstone quarrying has altered little over the last half century. An aspect which has changed, however, is the calcining of ore. The calcining process removes the volatiles, mostly carbon dioxide and water, thereby raising the percentage of iron in the ore. It was carried out on the floor of the quarry by burning coal mixed with ore before loading it for transport to the ironworks. Coal costs have made this process uneconomic in recent years and it is now no longer carried out. The sequence of events illustrated in Fig 18 shows how ironstone was worked in the 1920s. With the exception of the calcining stage, it can still be seen at numerous places in the East Midlands. A dragline excavator travelling parallel to the ironstone face (1 and 2) removes the topsoil and overburden. The overburden is dumped opposite the place from which it is taken on ground from which the ironstone has already been removed. Topsoil is replaced and levelled, and the land restored to agricultural use. Having stripped a length of ironstone, the dragline dumps coal slack on the newly exposed surface. A steam navy following behind digs out the ironstone and deposits it, with the slack intermingled, on lump coal spread out on the ground behind it. The whole heap is fired at intervals as the excavator advances. Calcination is complete in about 8 weeks (4), after which the ore is lifted into railway trucks and taken to the ironworks (5). At the end of the working face the excavators return to the starting point for another cut and the railway track is moved laterally forward to the edge of the new face. Today ore, which is usually blasted with explosives, is lifted straight from the bed of the quarry into railway trucks or lorries.

The principle of all conventional ironmaking processes involves the removal of the oxygen from the ore by reduction. Carbon in the form of charcoal or coke combines with the oxygen of the ore to release metallic iron and gases. In modern blast furnaces oil is also injected. Wrought iron was made by heating a mass of iron ore in a charcoal fire to create a spongy lump or bloom which could then be hammered into tools or weapons. The iron was not melted, the hammering or forging process being fundamental in the removal of many of the final impurities. This direct process was the only way of converting iron ore into metal until about the fifteenth century when furnaces of sufficient size, using hand or more often water-powered bellows, to increase the temperature, could melt the iron into a liquid state. This new iron, or cast iron, was probably at first an accidental by-product resulting

# IRONSTONE WORKING IN THE EAST MIDLANDS

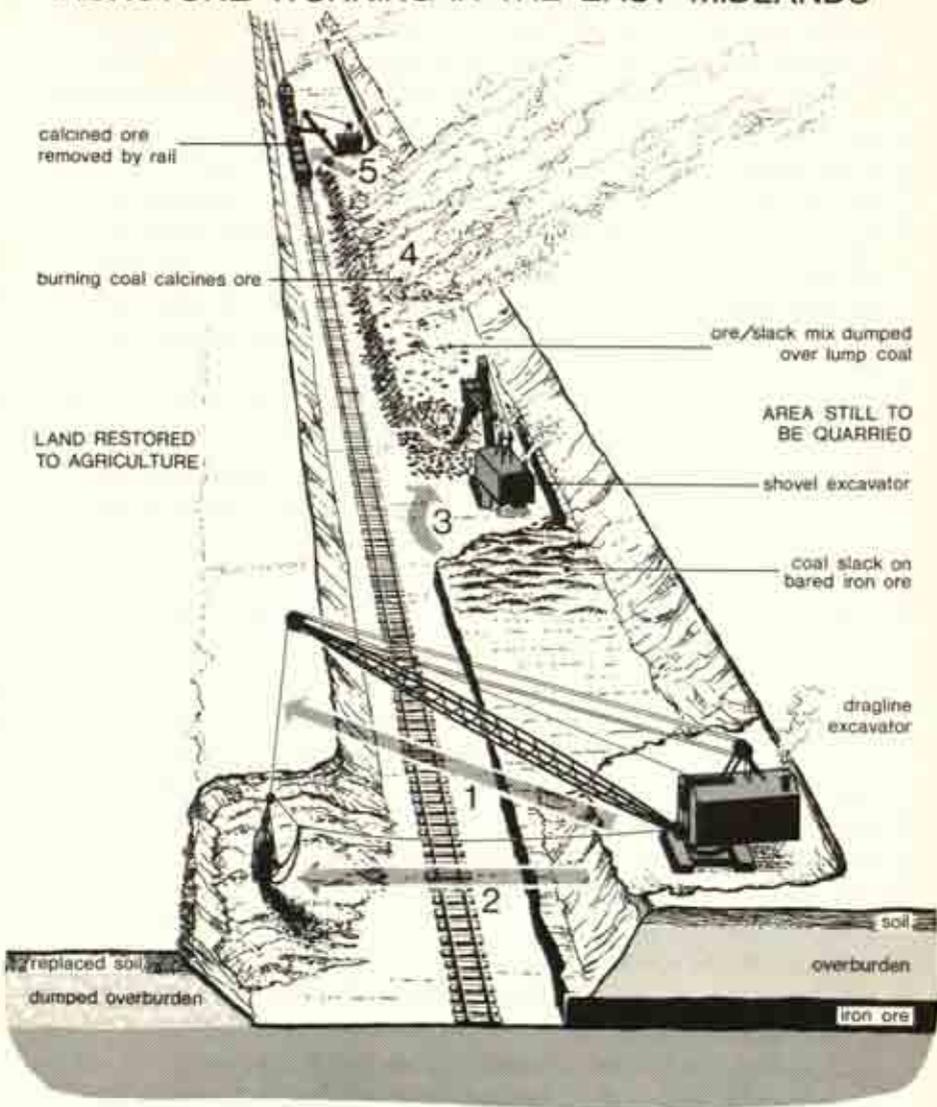


Fig 18

from the overheating of a bloomery furnace. It could not be shaped by hammering and its hard, brittle nature meant that there were at first no obvious uses to which it could be put. It was soon realised, however, that the production of cast iron could be a short cut to larger quantities of good quality wrought iron, and in this manner the iron smelting industry, based on the charcoal-fuelled blast furnace, came into existence.

The origin of the blast furnace is obscure but it is generally thought to have developed in what is now Belgium before AD 1400. The blast furnace enabled much larger quantities of iron to be produced than the old bloomery, as much as a ton in 24hr as compared with a few pounds previously. Cast iron from the blast furnace was run as a liquid into depressions in a bed of sand, the main runner being the sow and, for obvious reasons, the side branches being called pigs (Fig 19). Pig iron is still made, although now by machines, the size of the pig being determined by convenience of handling. By the sixteenth century objects such as firebacks, cannon and cannon balls were being cast, but cast iron remained of relatively minor importance until the early eighteenth century when it was to become the most vital of raw materials to the civil and mechanical engineer.

The primary object was still the production of wrought iron, which was achieved in two stages in the finery and chafery. During the smelting process the pig iron had absorbed a number of impurities, notably carbon, and, if the temperature was high enough, silicon. The finery was a charcoal-fired hearth, similar to a blacksmith's hearth, in which the iron was stirred at high temperature under a blast of air from bellows. The oxygen in the air blast combined first with the silicon, which was driven off in the form of  $\text{SiO}_2$ , and then with the carbon to form  $\text{CO}$  and  $\text{CO}_2$ . As the iron became purer, its melting temperature would rise, resulting in the coagulation of a spongy mass of iron in the hearth. This was hammered into a rectangular block weighing about  $\frac{1}{2}$ cwt before being transferred to the chafery. The chafery, unlike the finery, had no secondary blast of air and was simply for reheating the iron to forging temperature so that it could be fashioned into a shape suitable for marketing. The iron was not melted and no change in its chemistry occurred. Charcoal was the normal fuel in the chafery, but as iron absorbed very few impurities when in the solid state, it was in the chafery that the relatively 'dirty' fuel, coal, was first adopted. The finery and its ancillary equipment, of which the hammer was the most important, was

known as a forge, a term which is still used today for any works where iron is fashioned. Strictly, the term originally applied only to the building containing the finery where wrought iron was manufactured.

The bloomery furnace, and the later finery and chafery, all needed hammers, both to beat the impurities out of the iron and to shape it. These were water-powered tilt hammers, each consisting of an iron hammer head on a wooden haft working on to an anvil. The tail of the haft was depressed by a series of cams on the axle of the waterwheel and, as the head was raised, it was pressed against a wooden spring beam which ensured that, when the cam released the hammer, it would fall with a considerable and consistent force. None of these early hammers survive in complete form, although the Weald & Downland Museum near Singleton in Sussex (181/SU 875130) has a hammer head and wheel shaft. Later, forging hammers known as helves were introduced for fashioning metal and some of these operated on the same basis as the early tilt hammers (Fig 22).

The importance of a supply of water for working tilt hammers applied equally to the blast furnace, where bellows had to operate continuously for weeks at a time. Indeed, water to power the bellows which blew the air into the furnace was a primary resource of the iron smelting and wrought-iron making industries, and an important factor in determining the general location and detailed siting of a furnace or forge. This significance can be fully appreciated from the fact that for every ton of iron smelted up to 4 tons of air were required. Today the pools which supplied the water-powered bellows and hammers of early ironworks are often the only tangible evidence of their existence, particularly in the South East, where the so-called 'hammer pond' is a familiar feature. Good examples, all in St Leonard's Forest, Sussex, are Hawkins Pond (182/TQ 217292), Hammer Pond (182/TQ 219289) and Slaugham Pond (182/TQ 248281). At each of these sites the earth dam survives intact, now carrying a minor road, and the drop necessary to provide adequate power and the quantity of water which had to be stored to ensure continuity of operation of the forge are well demonstrated.

The production of cast iron in blast furnaces expanded considerably during the sixteenth and seventeenth centuries, spreading from Sussex to the Midlands after 1561 and reaching the Lake District in 1711. The principle on which the blast furnace operated was relatively simple, although some of the chemical changes occurring within it during the smelting of a charge of

# CHARCOAL BLAST FURNACE CUT OPEN TO SHOW INTERIOR

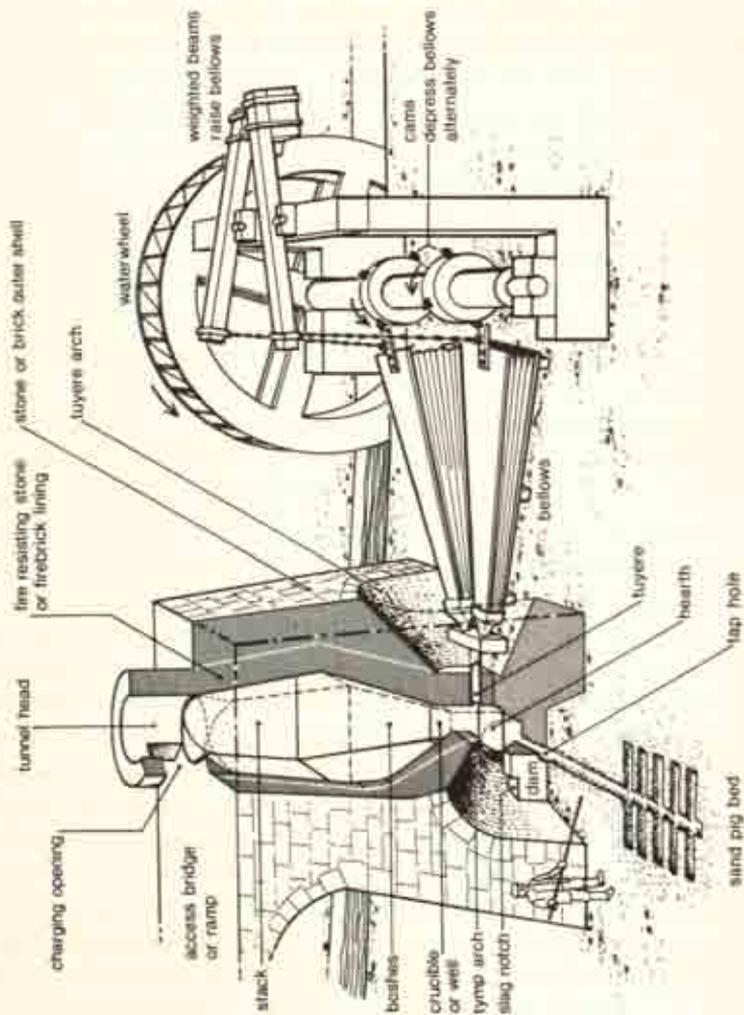


Fig 19

iron ore are quite complex and were probably not understood in any detail until the beginning of the nineteenth century. An early type of charcoal blast furnace is illustrated in Fig 19. In cross section it is shaped rather like a chimney with a narrow top to the stack widening gradually to the top of the boshes. The walls then slope inwards and become vertical in the hearth. There were numerous variations in this shape but the basic arrangement has been maintained down to today and still applies to modern steel-cased furnaces. The example illustrated has a square inside section to the stack; by the end of the seventeenth century blast furnaces were almost invariably circular in working section although still maintaining a rectangular outer shell.

The blast furnace operated continuously with iron ore and charcoal charged in at the top and gradually descending through the stack. In the upper part water and other volatiles such as carbon dioxide would be driven off and in the lower section the ore was reduced to metallic iron. The increase in diameter of the stack from top to bottom lessened the tendency for the charge to stick. At the top of the boshes the earthy impurities in the ore fused to form a slag and molten slag and iron were funnelled down into the hearth, where the denser metal lay at the bottom with the slag floating on top of it.

At the same time water-powered bellows blew air into the hearth through the tuyere (pronounced 'tweer') and this reacted with the charcoal to give carbon dioxide and heat and the carbon monoxide which reduced the ore by combination with the oxygen in it. As the iron trickled through this hottest part of the furnace around the tuyere, it would dissolve carbon out of the unburnt charcoal, which accounted for the high carbon content of the resulting cast iron. At intervals the slag was drawn off through the slag notch at one side of the fore arch, and when sufficient iron had accumulated in the bottom of the hearth, the clay plug in the tap hole was broken and the molten iron flowed out down a channel to the pig bed. During the sixteenth and seventeenth centuries most of the iron was run into pigs for eventual conversion into wrought iron, but if objects such as cannon were required, they were cast direct from the blast furnace. The direct technique of casting remained common until the latter part of the eighteenth century.

A typical site for one of these early furnaces would be on a fairly steep

slope so that an access bridge or ramp, the 'bank' could easily be built from the hillside to the top of the stack for charging. The side of an existing watercourse was particularly suitable. At the foot of the slope there had to be ample space for the pig bed, which was often covered by a casting shed and the bellows, which might be 20-25ft long and 5ft wide at their outer ends. Other buildings associated with such a blast furnace were the charcoal store, which was usually a large barn-like building, and often an iron ore store. A particularly good example of an eighteenth-century charcoal blast furnace, where many of the ancillary buildings still survive, although in ruins, is at Duddon Bridge in the Lake District (88/SD 197884). The furnace was begun in 1736 and finally abandoned in 1867. Numerous other furnaces can be traced in the same area, including one at Newland (88/SD 299798) where the casting shed survives complete, and another on Leighton Beck, south-east of Arnside (89/SD 485778) where, although the furnace itself has disappeared, a large barn that was almost certainly the charcoal store can still be seen. At Charlcombe in Shropshire (129/SO 638861) is a well preserved blast furnace with an almost complete lining and cast-iron beams over the fore arch and tuyere arch supporting the stack. There are no ancillary buildings surviving on the site. Another good example, preserved by the Department of the Environment is at Bonawe in Argyllshire (35/NN 114770).

Charcoal was used exclusively as the fuel in all early blast furnaces, and this led to huge areas of the country being almost completely denuded of trees. Some furnaces consumed the wood from over 150 acres of forest in a year, with the result that the nation's timber resources, particularly in the South-East where there were the competing strategic needs of the Royal Navy, became seriously depleted. Before the end of the sixteenth century legislation was introduced to control the consumption of woodland and so, as the Wealden industry gradually died, ironmasters were driven to more remote sites in the border country of the River Severn, in Wales itself, the Lake District and Scotland, always seeking the vital combination of iron ore, wood for fuel and water for power.

What was to prove one of the major technological breakthroughs of the early Industrial Revolution occurred in the first decade of the eighteenth century with the perfection of a technique for smelting iron using coke as a fuel instead of the traditional charcoal. There had already been numerous attempts to use coal, of which the unsuccessful efforts of 'Dud' Dudley

(1599-1684) are the most notorious, but in none of these experiments was the fundamental problem of contamination of the iron by impurities in the coal overcome. The coke smelting process was developed in Coalbrookdale, Shropshire, in 1709 by the Quaker, Abraham Darby (1667-1717), who had recently come from Bristol to take over an existing charcoal blast furnace set up about 1638. The geological circumstances which led to Darby's success are significant and undoubtedly contributed greatly to the establishment of Coalbrookdale as a major centre of ironfounding technology by the second half of the eighteenth century. The key lay in the local 'clod' coal, which, although not a coking coal in the modern sense of the term, was ideal for iron smelting. The process of coke manufacture was essentially similar to that of charcoal burning in that coal was burned in conditions starved of oxygen in low mounds or clamps, thus driving off the volatile components. The clod coal of Shropshire is of relatively low rank, with a carbon content of 78-9 per cent, and will not 'cake' like normal good quality coking coal. It can, however, be successfully coked in large lumps and, of particular importance for iron smelting, it has an extremely low sulphur content. Thus clod coal produced a coke closer in its resemblance to charcoal than almost any other coal in Britain. It was indeed a fortunate coincidence that Darby should come to a place where an eminently suitable fuel occurred in close proximity to good quality clayband ironstones from the Coal Measures. An additional, although less significant factor was the availability of limestone, which was essential to the coke smelting process as a fluxing agent. It is likely that limestone was added to the blast furnace charge as early as the sixteenth century, and certainly by the beginning of the eighteenth the technique was well known. The object of the flux was to assimilate the various impurities in the iron ore, which could then be easily run off as slag.

Darby's technique was of immediate benefit to him, as the major output from his Coalbrookdale furnace consisted of cast-iron domestic products rather than pig iron for conversion to wrought-iron. There were initial difficulties, however, in using coke-smelted iron for this purpose, and the new smelting technique did not become widespread until the 1760s. By that time Coalbrookdale was thriving, using coke-smelted iron and also developments of foundry techniques patented by Abraham Darby in 1707. The patent for 'casting Iron-bellied Pots and other Iron-bellied Ware in

Sand only without Loam or Clay' contains no technical details but it may be assumed that Darby had devised what is basically the modern method of dry-sand moulding in conjunction with multi-part moulding boxes. The bellied pots for which Darby obtained a patent were three-legged cauldrons with a maximum diameter in the middle, and they were to become a typical early product of the Coalbrookdale Company which he formed.

By the second half of the eighteenth century Coalbrookdale's ironfounding expertise was widely known. As early as the 1720s Coalbrookdale had been casting cylinders for Newcomen steam engines in iron instead of the traditional brass. The first iron rails were cast there in 1767 and at the end of the following decade the components for the first iron bridge, the first civil engineering work in the world in which cast iron, or indeed iron of any type, played a structural role. By the end of the eighteenth century cast iron was accepted as the major raw material of the civil and mechanical engineer, to be used for steam engines, the columns and beams of mills and warehouses, tramway plates, bridges and aqueducts and innumerable smaller machinery components. Coke-fuelled blast furnaces were being built by the dozen, and in areas where the iron industry had hitherto been non-existent. Indeed the distribution of the iron industry was essentially a reflection of that remarkable geological coincidence which contributed so much to the Industrial Revolution in Britain and the nation's industrial supremacy in the succeeding century — the occurrence in the same series of measures, and often very near the surface, of ironstone and coal admirably suited to the available technical processes of coke manufacture and iron smelting. Coal of the clod type occurred in South Staffordshire in the famous 'Ten Yard' seam, in West and South Yorkshire, and in South Wales, where a denser and less reactive coke resulted in blast furnaces being generally taller than elsewhere. North Wales, Derbyshire and to a lesser extent Scotland also developed coke-based iron smelting, although in Scotland the 'splint' coals gave a rather lower yield coke and the great expansion of the iron industry there had to await further technological developments after 1820.

In 1760 there were perhaps ten blast furnaces using coke throughout Britain at sites including Cumberland and South Wales and the famous Carron foundry in Stirlingshire. Fourteen more were erected in the 1760s and early 1770s, but the greatest increase took place from 1775 onwards. By 1790 only twenty-five charcoal blast furnaces were still in operation

compared with eighty-one working on coke, of which thirty-five were in the Midlands (twenty-four in Shropshire and eleven in Staffordshire). The best results from coke smelting were not obtained until a stronger blast could be developed than that provided by the old water-powered bellows. In 1757 Isaac Wilkinson introduced cast-iron box bellows, to be followed in 1760 by John Smeaton's invention of the cast-iron blowing cylinder, which was basically a piston moving in a large diameter cylinder to provide blast. Both these devices were water-powered, however; it was not until the introduction by James Watt in 1775 of a steam blowing engine at John Wilkinson's Willey furnaces in Shropshire that the coke blast furnace became really efficient and, for the first time, was freed from its stream or riverside site.

Evidence of this vital period in the development of ironmaking is readily visible in the Coalbrookdale area of Shropshire (Plate 22). In the Dale itself the now modified furnace in which Darby first smelted iron using coke as a fuel (119/SJ 667047) is preserved by the Ironbridge Gorge Museum Trust, and nearby is a small museum of ironfounding illustrating the evolution of the cast-iron industry after 1709 and displaying examples of the Coalbrookdale Company's products. The furnace itself (Plate 23), which is one of Britain's primary industrial monuments, has cast-iron beams supporting the fore arch, of which the lower two are from the original charcoal blast furnace, one being dated 1638. The two upper beams date from 1777 and were added by Abraham Darby III (1750-91), probably to increase the capacity of the furnace sufficiently to cast the ribs of the Iron Bridge. Lower down the valley of the Severn at Ironbridge are the Bedlam furnaces (119/SJ 677034), which have recently been restored. These furnaces date from 1757 and were some of the first to be built specifically for coke smelting. Originally there were two furnaces side by side, with bellows powered by waterwheels in wheelpits behind. Water supply was extremely poor, however, and a steam engine was employed to lift water from the nearby river to run the wheels. In every other respect the Bedlam furnaces were a model of efficient layout, with tramways running down-slope to the charging platform to feed in iron ore, coke and limestone and a pig bed stretching almost to the banks of the Severn, where there was a wharf against which the Severn trows (sailing barges) could tie up. Like the Coalbrookdale Company, Bedlam was dependent



22 The blast furnace in Coalbrookdale, Shropshire, where Abraham Darby perfected the technique of smelting iron ore with coke in 1709. Excavation of the furnace site in the late 1950s

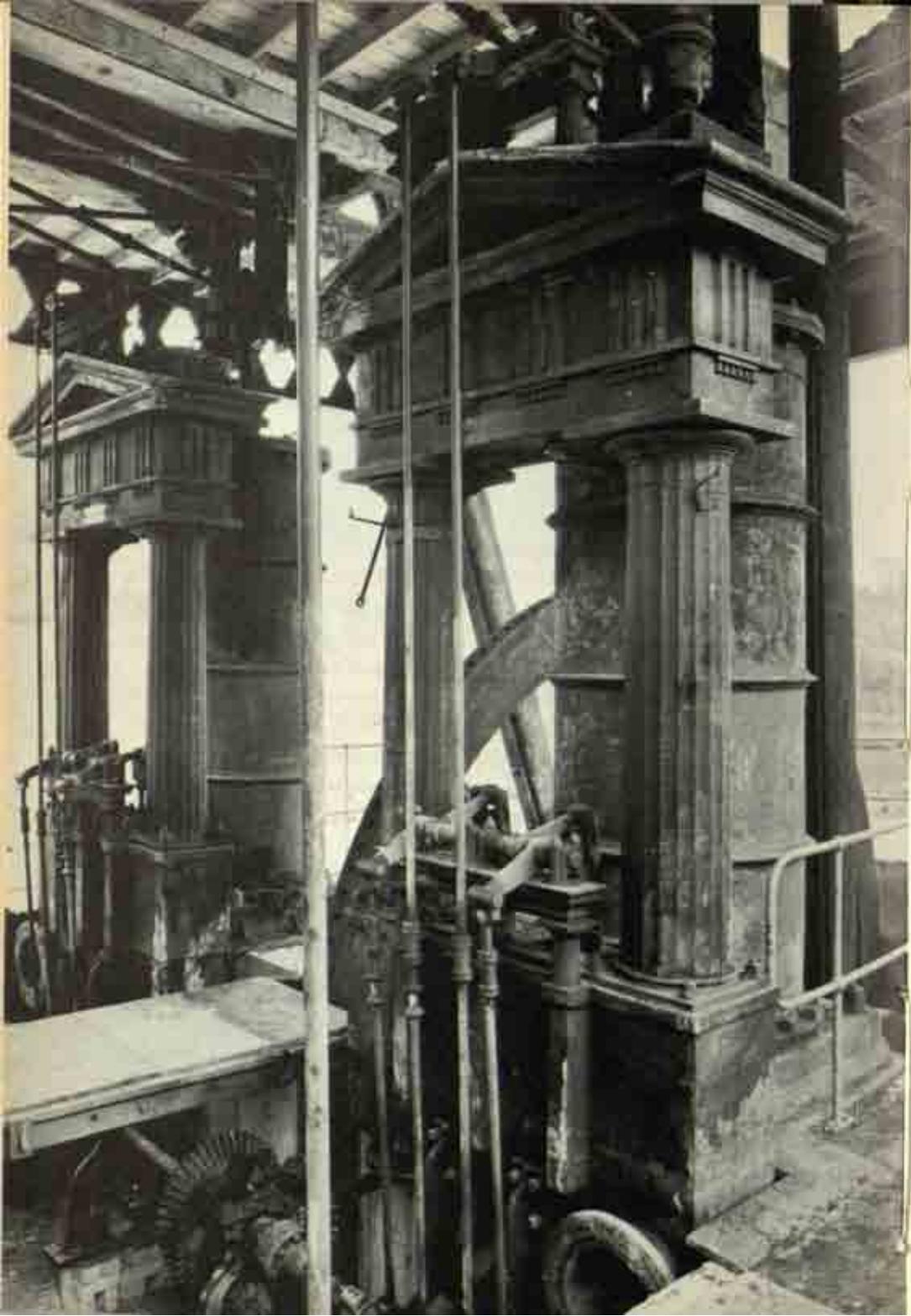
23 Abraham Darby blast furnace, Coalbrookdale, Shropshire. Detail of beams over forehearth



on water transport as a means of getting its iron—in this case good quality foundry iron—away to market.

At some date after their construction the Bedlam furnaces were modified to use a steam blowing engine, and today evidence of this can be seen in the form of the three tuyere arches, each of which still contains its cast-iron tuyere pipe. Air was conducted from the engine via the blast main, part of which remains at the back of the furnace, to the tuyeres by iron pipe. Although no tangible evidence of the engine can now be seen, two nineteenth-century blowing engines are preserved by the Trust at the Blists Hill Open Air Museum about  $\frac{1}{2}$  mile downstream from Bedlam (119/SJ 693033). One consists of a pair of beam engines (Plate 24) driving a common crankshaft and flywheel. Known as *David and Sampson (sic)* these engines were built in 1851 by Murdock, Aitken of Glasgow for the Lilleshall Company of Oakengates, Shropshire. They worked until the 1950s and were eventually saved from destruction and re-erected at Blists Hill. Also at the Blists Hill museum are the remains of three mid-nineteenth century blast furnaces, with the houses that originally held two steam blowing engines (Plate 25). A vertical blowing engine, one of the last generation of reciprocating steam blowing engines to be built before the introduction of modern electric turbo-blowers, has been reinstalled in one of these houses.

By the time these blowing engines were in use another major development in blast furnace technology had occurred, although, largely as a result of prejudice, superstition and old habits dying hard, it took a number of years to become universally accepted. All blast furnaces until the 1820s had depended on atmospheric air blown through tuyeres by water-powered bellows or steam blowing engines. In 1828, however, James Neilson (1792–1865) of Glasgow patented the technique of preheating the blast air using stoves with coal grates, which were installed and operated successfully on a furnace at the Clyde Ironworks in the early 1830s. They raised the air temperature substantially, achieving in due course a saving of 20 per cent in furnace fuel. In 1857 the process was further developed by E. A. Cowper, who applied successfully the regenerative principle used today. In the Cowper stove air on its way to the blast furnace is blown through and heated by checkerwork columns of firebricks which have previously been heated by the combustion of waste gases from the same blast furnace. Using two or more stoves, heat is generated in one while air is blown through another. Alter-



25 Vertical blast-furnace blowing engine, preserved at the Blists Hill Open Air Museum, Ironbridge, Shropshire



nation of the flow assures a constant supply of hot air for the blast, which reaches a modern furnace at about  $1,000^{\circ}\text{C}$ . Cowper stoves, introduced for the first time at Ormesby near Middlesbrough in 1860, are still used today, and their cylindrical forms with convex tops are a typical feature of most modern ironworks.

The application of hot blast, which was perhaps the greatest single improvement made to the technology of the blast furnace, resulted in a great increase in iron output and efficiency of fuel utilisation. It also meant that with the much higher temperatures involved, certain types of raw coal

24 Steam chests of the double-beam blast furnace blowing engines *David and Sampson* 1851, preserved at the Blists Hill Open Air Museum, Ironbridge, Shropshire

could be used instead of coke, and notably the blackband ironstones of Scotland with their splint coals. In South Wales, too, anthracite firing was used extensively after 1837, when George Crane introduced the process at Ynyscedwin. On-site evidence of cold and hot blast furnace practice is usually easy to find. Cold blast slag is of a glassy nature, has a conchoidal (shell-like) fracture, is usually blue and green, and is hard and valuable as hardcore or road metal. Hot blast slag on the other hand is a dull whitish grey and shaly, with a tendency to slake down to a fine mud when wet, although today it is also used extensively for aggregate and railway ballast. The coke smelting technique developed by Darby was acceptable when a perfect combination of raw materials was used, but there were distinct disadvantages when this was not the case. With a few exceptions, coke furnace pig when converted into *wrought* iron produced metal so brittle that it crumbled under the hammer. Much *cast* iron produced by coke furnaces also had a low strength, with a pronounced tendency to crack. The reason was that coke contained more impurities than charcoal, the quantity of ash was higher and sulphur and phosphorus were often present. In Britain the presence of phosphorus was a particular disadvantage, as many of the iron ore deposits which were being worked in the eighteenth century were themselves also phosphoric. In addition, not all the coal being used for coking had the same sulphur-free characteristics of the clod coal of Coalbrookdale.

The answer to the problem of poor quality cast iron was the remelting furnace in which coke-smelted pig could, in effect, be refined, thus improving its purity and homogeneity. The first remelting furnaces developed in Britain in the early eighteenth century were of the reverberatory type in which the iron did not come into direct contact with the fuel, which was usually coal. The name 'cupola' was given to these furnaces which were similar in general arrangement to puddling furnaces (see Fig 20). The modern cupola, which became the standard means of remelting iron, was devised in the 1790s by John Wilkinson (1728-1808) and consisted of a vertical shaft rather like a miniature blast furnace. It was used for melting iron, not for smelting, and in its smallest form often consisted of a barrel perhaps 3ft in diameter and 10ft high made of cast-iron staves held together with wrought-iron hoops. It was lined with refractory bricks or cement and fired with coke. A very early example, possibly dating from the 1820s, is preserved at the

## IRON PUDDLING FURNACE

CUT OPEN TO SHOW INTERIOR

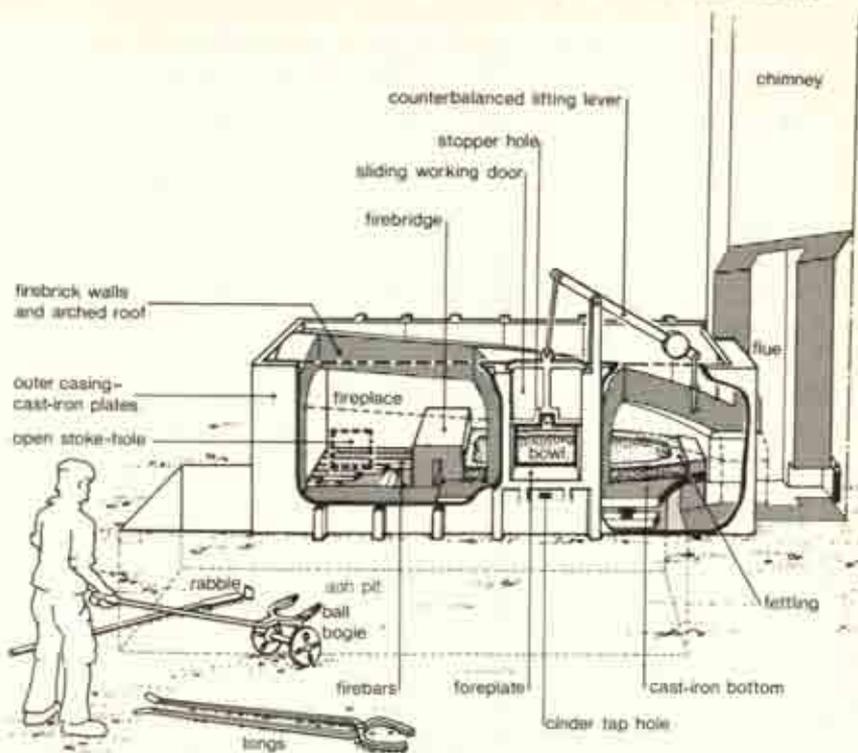


Fig 20

*Blists Hill Open Air Museum.*

A large late nineteenth-century cupola furnace is shown in Fig 21. It has a shell of rolled steel plates and a firebrick lining, and is similar in most respects to the modern cupola that is such a typical feature of foundry areas like the Black Country. Broken pig iron, scrap cast iron and coke were fed in at the charging level, and molten iron drawn off in small quantities at the tap hole as required. The iron would be either run down channels to moulds in a sand bed or caught in hand ladles and taken direct to the moulds. Although direct casting from the blast furnace continued for certain applications, the cupola almost completely replaced this technique by the end of the nineteenth century. Initially blast was provided by water-powered or even

## CUPOLA FURNACE

CUT OPEN TO SHOW INTERIOR

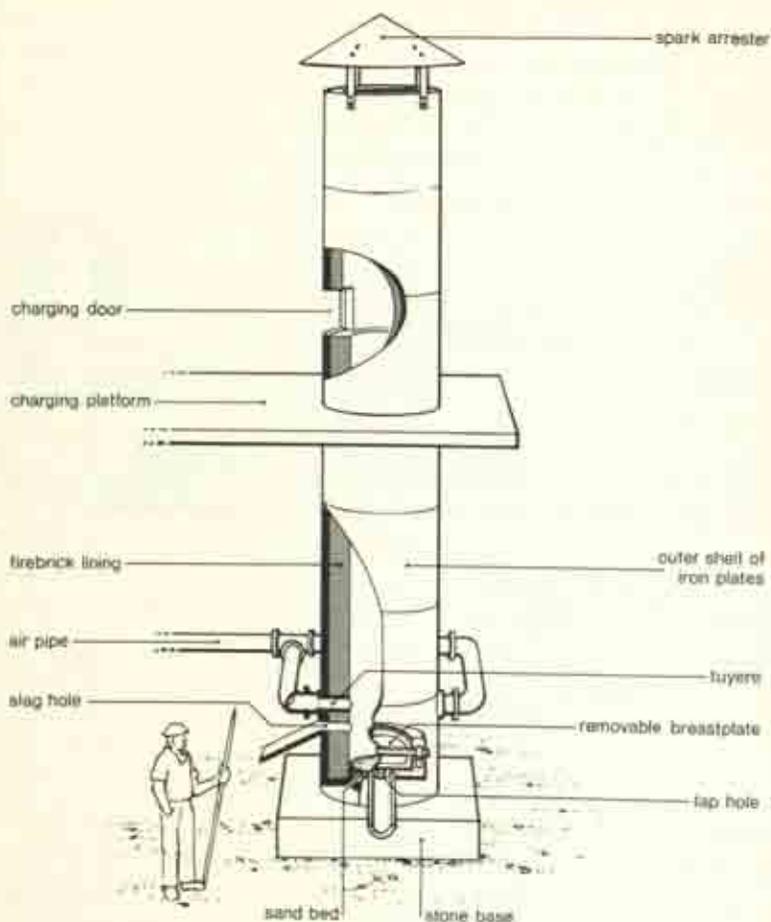


Fig 21

hand bellows, but now electric blowers are employed.

The other difficulty of making satisfactory *wrought* iron with coke-smelted pig was finally solved in the 1780s. Experiments with reverberatory furnaces using coal as a fuel were being conducted in Coalbrookdale in the 1760s by the brothers Thomas and George Crange, who took out a patent for 'making pig or cast iron malleable—in a reverberatory or air furnace,

with raw pit coal only' in 1766. For reasons unknown, this process and a similar one patented in 1783 by Peter Onions, were not brought into commercial use. Final success was achieved by Henry Cort (1740-1800) of Funtley, Hampshire, who patented a workable puddling furnace in 1784. Cort's process consisted essentially of stirring molten pig iron on the bed of a reverberatory furnace until, through the decarburising action (removal of the carbon content) of the air which circulated through the furnace, the pig became converted into malleable iron. In this process contact between the molten metal and the raw coal which was used as a fuel was avoided and blowing machinery could be dispensed with. An important contributory factor to Cort's success, however, was his use of grooved rolls which he included in his patents despite their previous use. The combination of the puddling furnace and the use of grooved rolls to produce iron bar led to an immediate and spectacular increase in the output of wrought iron and provided an additional stimulus to the changeover from charcoal to coke smelting of iron ore. Watercourses and slag can still be found at Cort's Funtley site (180/SU 550082) but no buildings or equipment survive.

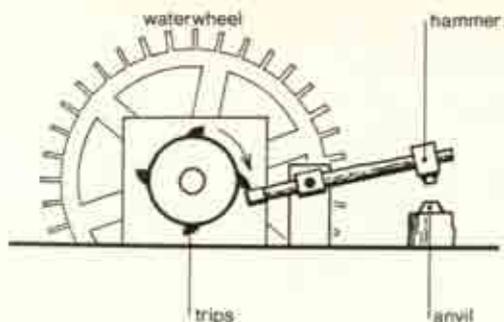
There was, however, one major shortcoming of Cort's puddling process: it was wasteful of iron, which tended to combine with the sand floor of the furnace to form a useless siliceous slag. An initial improvement was effected by Samuel Rogers of Nantyglo, Monmouthshire, who in 1818 substituted a cast-iron plate and iron oxides for the sand bottom, but the real breakthrough came about 1830 as the result of the 'pig boiling' process developed by Joseph Hall (1789-1862) of Tipton, Staffordshire. Hall used a cast-iron tray for the bottom of the furnace, in which 'fettling' of oxidised compounds of iron such as cinder or mill scale was laid. The pig boiling process consisted of the decarburisation of the pig iron by contact with the molten oxidised compounds. These combined with the carbon in the pig to form carbon monoxide, which burst to the surface of the iron—hence the term boiling—where it burnt with blue flames known as 'puddlers' candles'. Hall's process, because the iron was molten, became known as 'wet' puddling, in contrast to 'dry' puddling, which was done on sand bottoms. The wet puddling process became universal, to the complete exclusion of Cort's and is the one practised today in the only works now producing wrought iron in Britain, Messrs Thomas Walmsley & Son of Atlas Forge, Bolton, Lancashire (101/SD 713084).

Fig 20 shows a typical nineteenth century wet puddling furnace of the type still used, although today oil instead of coal is the fuel. Flames from the fireplace on the left were drawn across the bowl of broken pig iron and up the flue. An initial period of melting took place in which most of the silicon, manganese and some of the phosphorus in the pig oxidised and passed into the cinder settling. The damper in the flue was then partially closed to 'smother' the furnace while the remainder of the silicon and manganese and most of the phosphorus went into the slag. At this stage 'boiling' began with the carbon combining with oxygen and burning at the surface as puddlers' candles. Throughout this stage the puddler stirred the iron with a rabble until all the carbon had burnt off and the remaining phosphorus was removed. The iron was by now almost pure and, as its melting point rose, it coagulated to be gathered into four or five spongy balls and removed on a ball bogie to a hammer, where the liquid slag in the interstices would be hammered out and a roughly rectangular lump or bloom suitable for rolling would be formed. Hammering, or shingling as it was called, was initially carried out under a water-powered hammer or helve, of which there were three basic types (Fig 22), all of which were operated by cams on a water-wheel shaft. The type normally used for shingling was the nose or frontal helve, with a head of 5-8 tons in weight. At one end was the fulcrum and at the other the cams. Frequently these nose helves were steam-powered, but after the introduction of the steam hammer in 1839 by James Nasmyth (1808-90) they were gradually superseded and are now extinct. The other types of helve, used primarily for forging, will be considered later.

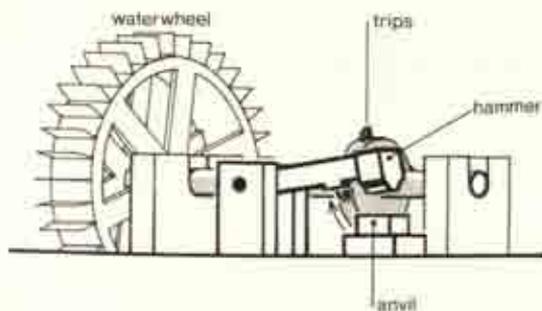
Once hammered into a rough bloom, the iron was ready for rolling, initially into a puddled bar or 'muck bar', and subsequently into smaller sections. Both the hammering and rolling processes were essential to improving the quality of the iron, which was sold according to the number of times it had been rolled. Thus muck bar, cut up, stacked in a pile, reheated in a mill furnace and re-rolled would become crown or merchant bar. The same process applied again produced *Best* iron, a further working resulted in *Best Best* or *BB* iron, and yet another rolling made the highest grade of all—*Best Best Best* or *BBB* iron.

Iron rolling had its origin in Britain in the slitting mills of the sixteenth and seventeenth centuries, which produced iron rod by cutting hammered plate into thin strips. From these developed the grooved rolls of the type

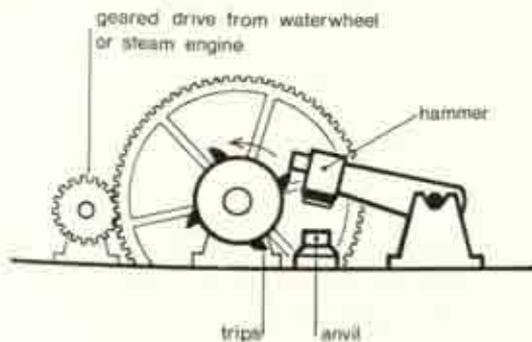
FORGING HAMMERS



Tail helve



Belly helve

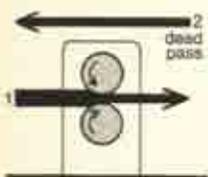


Nose helve

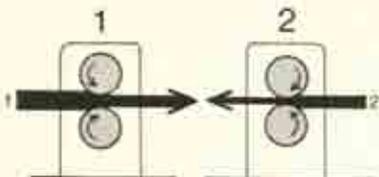
Fig 22

## ROLLING MILL TYPES

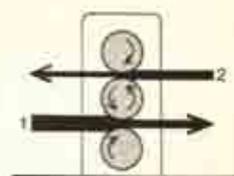
Two-high



Two-high reversing



Three-high



Continuous

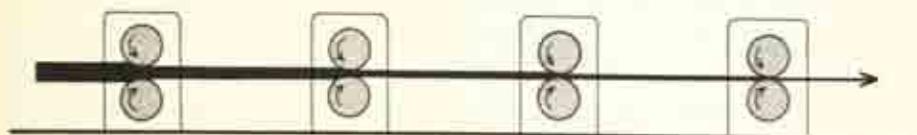


Fig 23

patented by Cort in 1784, which produced iron in round or square section, depending on the shape of the grooves. Fig 23 illustrates the various types of roll, of which the two-high mill was common until the beginning of the nineteenth century. The problem with a two-high mill, particularly for thin section iron, was that, having passed through the rolls in one direction, it had to be returned to the beginning—the dead pass—before it could go through the rolls again, during which time it was continuously cooling. The answer was the three-high mill, in which a third roll, the same size as the other two was mounted above them. Thus a live pass could be made in each direction, the iron going out between the lower and middle rolls and returning between the middle and upper ones, work being done in both directions. Three-high mills are thought to have been introduced into Staffordshire before 1820, but they were not widespread until the 1860s. Also in the 1860s George Bedson of Manchester developed the continuous rolling mill (Fig 23) consisting of a number of two-high stands placed one behind the other. The reversing mill, in which the hot metal was passed backwards and forwards (Fig 23, stages 1 and 2), was introduced first at

Crewe locomotive works in 1866. A very old, probably eighteenth-century, two-high mill for making small section rounds can be seen at Wortley Top Forge (102/SK 294998) between Deepcar and Thurgoland near Sheffield, while Blists Hill Open Air Museum has a set of three-high rolls.

Before leaving the iron manufacturing industry it is worthwhile considering further some of the secondary ironworking processes so closely tied up with it. In both the manufacture of cast iron and wrought iron, continuations of the ironmaking process led through to the manufacture of finished articles. In the former case iron castings were initially made direct from the blast furnace and later by melting pig or scrap in a cupola furnace. Thus the foundry industry became separated from the smelting process and is now widely distributed throughout the country. Similarly with the wrought-iron industry rolled bar or rod of the appropriate quality was the usual end product of a puddling works. Numerous industries, however, used wrought iron as a raw material, some of them employing similar equipment to that found in the ironworks themselves. These are worth considering here.

An example is Top Forge at Wortley (102/SK 294998), already mentioned. Although parts of the surviving buildings may date from the seventeenth century, most of the machinery is nineteenth century, the period of the forge's greatest prosperity, when wrought-iron railway axles were made there. The oldest hammer, or helve, is nearest to the wall of the dam which once supplied the water power for its operation. The helve itself is of wrought iron (Plate 26) but originally it would have been of timber strengthened with iron hoops. It is of the belly helve type (Fig 22) with the cams on the shaft lifting the hammer between the fulcrum and the head. Wagon axles were made from faggots of 16in square iron bars heated to welding temperature and forged to shape under the hammers. A rolling mill was installed in the 1780s and iron puddling may have been carried out slightly later. All work ceased in 1912. The forge, which is being restored by the Sheffield Trades Historical Society is open to the public each Sunday (Plates 26 and 27).

Another preserved site where iron products were made is Finch Foundry at Sticklepath (175/SX 639940) near Okehampton in Devon. Here from 1814 until 1960 agricultural tools such as scythes, billhooks and shovels were made by successive generations of the Finch family. The machinery,



26 Wortley Top Forge, Yorkshire. Water-powered helve hammers

most of which is still in place, was powered by the River Taw and includes a pair of hammers of the tail helve type (Fig 22). A second waterwheel drove a fan to provide air to the various forges, while a third powered grinding wheels where the tools were sharpened. The foundry is being restored by the Finch Foundry Trust and much of the equipment can be seen in operation.

The availability of wrought iron in quantity from the end of the eighteenth century was almost as fundamental in its effects as that of cast iron produced by coke smelting a century earlier. The reputation of South Staffordshire bar, for example, became well established in the early years of the nineteenth century when Captain, later Sir, Samuel Brown (1776–1852) persuaded the Royal Navy to use iron chain instead of bulky hemp anchor cable. In 1813 he made a testing machine to measure the breaking stress of the iron and of the cable made from it. Today the remnants of the numerous chain shops linger on in the Cradley Heath area near Dudley where one or two works, such as those of Noah Bloomer (131/SJ 929862) still hammer-weld chain links by hand. A reconstructed chain forge can be seen at the



27 Wortley Top Forge. Eighteenth-century iron rolls

Avoncroft Museum Buildings, Stoke Prior, near Bromsgrove (131/SO 950684). Dudley Museum also has an 'oliver', the almost universally applied foot-operated hammer used in wrought-iron forges of the Black Country.

Samuel Brown developed further his interests in wrought iron, which he used for the chains of the Union Bridge near Berwick (64/NT 934510), and soon Telford was also using chains for his great suspension bridge at Menai. So great was the increased efficiency of production and volume of use of wrought iron in the early years of the nineteenth century that it dropped in price by 60 per cent between 1806 and 1830. From the mid-1820s rolled iron rails for the new steam railways were introduced. By the 1840s Brunel was using wrought-iron plate for his *Great Britain* steamship, and Stephenson was using wrought iron for the Britannia tubular bridge, the first of a whole generation of large wrought-iron railway bridges. About the same time the first wrought-iron girders were being fabricated from rolled flats, tees and angles riveted together, and these were making

their appearance in large buildings by the late 1850s. A surviving example is in the Sheerness boat store of 1858 (172/TQ 910753). As a constructional material, wrought iron reigned supreme down to the end of the nineteenth century, almost completely ousting cast iron. It was itself soon to be superseded, however, by steel, which became available in quantity towards the end of the century and is almost universally used today.

Steel possesses a carbon content ranging from 0.1 to 1.7 per cent, depending upon its various applications, which initially were all related to its ability to take and keep a sharpened edge. These qualities were recognised from early times and it was made in very small quantities for such purposes as edging swords and tipping arrowheads. The first processes consisted of heating pure wrought iron in contact with charcoal so that it would absorb carbon. Subsequently numerous but not very successful attempts were made to manufacture steel direct from iron ore. In 1791, for example, Samuel Lucas heated a mixture of iron ore and reducing material such as charcoal, powdered bone or cow horn in a sealed crucible with the intention of producing steel. A similar process was devised in 1800 by David Mushet and another by John Hawkins as late as 1836.

The first reasonably successful means of producing anything more than the minutest quantities of steel was in the cementation furnace introduced early in the seventeenth century, probably from continental Europe. The process consisted of carburising wrought iron by sealing it in fireclay pots with a carbon-rich mixture, largely of charcoal, and heating it in a coal-fired reverberatory cementation furnace. The main improvement over earlier techniques was that the pots were sealed, thus ensuring good carburisation. The resulting steel, known as 'blister steel' because of its surface appearance, was generally of rather poor and inconsistent quality and lacked uniformity of composition through a section of the bar. A better quality was achieved by binding a number of bars into a 'faggot', heating and then forging and welding to give 'shear steel'. If the process was repeated, an even better 'double shear' steel was produced. After 1682 high quality Swedish iron was imported to Britain for conversion to steel, and cementation furnaces became established around Newcastle, the main centre of importation. It is in the North East that one of the few surviving cementation furnaces can be seen—the Derwentcote furnace (Plate 28) north-west of Hamsterley (78/NZ 131565), built in the early eighteenth century and used until 1880.

28 An eighteenth-century steel cementation furnace at Derwentcote, near Hamsterley, Co Durham



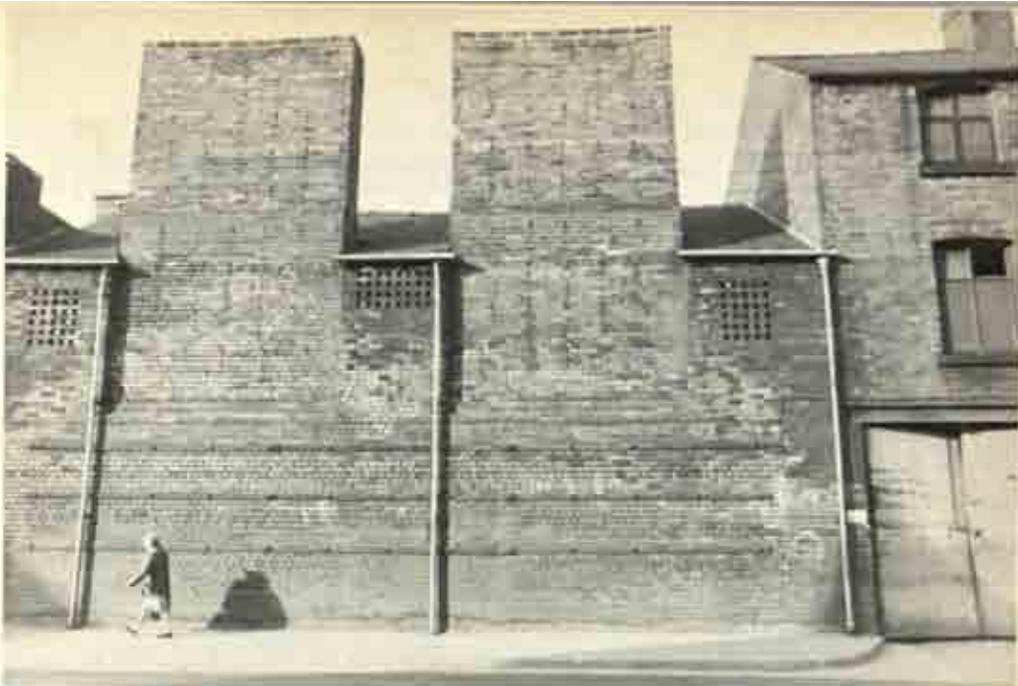
It is possible that the cementation process was brought from the North East to the Sheffield area, where in about 1742 Benjamin Huntsman (1704-76), a clockmaker from Doncaster, improved upon it with the 'crucible' technique in order to achieve a more uniform steel for springs and pendulums. After many failures, he finally found a method by which steel could be produced in a molten state. He melted bars of blister steel and subsequently iron and even scrap, with the addition of fluxes, in closed clay crucibles; the intense heat necessary was generated by coke. Two crucibles were placed in a chamber lined with firebrick, and the top of the furnace was closed by a cover of the same material, which was level with the floor of the melting house. A vaulted cellar gave access to the ash pit. Huntsman's process was



29 Crucible steel furnace,  
Abbeydale, Sheffield

far superior to those previously used and produced a uniform slag-free steel. In addition costs were reduced and output substantially increased.

Crucible steel was made at Abbeydale, near Sheffield, well into the present century (I11/SK 326820) on a site now maintained by Sheffield City Museums (Plate 29). Here it is possible to trace the manufacture of steel edge tools from the raw materials to the finished product. The crucibles in which the steel was produced were made here and the workshop where the clay was kneaded with bare feet before being made into 'pots', as they were called, is still extant. The high quality steel was made from a charge of iron and scrap, and sometimes steel scrap or blister steel, which was heated in the pot for about 4hr before the carbon was added. The pot was then lifted from the furnace (Plate 30) and, after any slag had been skimmed off, the

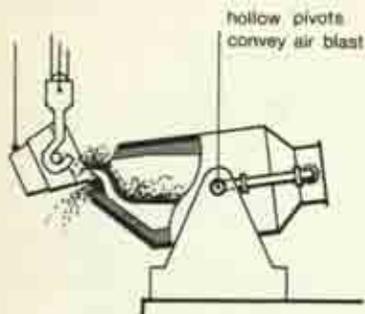


30 Crucible steel furnaces, Nursery Street, Sheffield

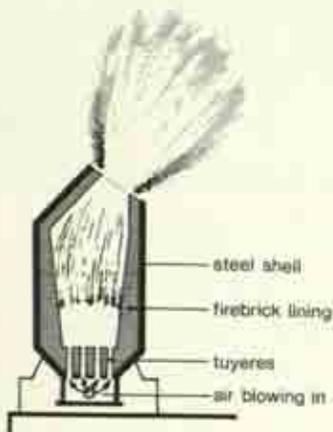
fluid metal was teemed into moulds and allowed to cool to a red heat before removal. When cold, the quality of the ingot was tested before being reheated and forged. At Abbeydale the reheating hearth has water-powered blowing cylinders and hammers under which the steel was sandwiched between outside layers of wrought iron. Thus great strength and reliability was given to the central cutting edge. There are various hand forges once used by craftsmen to temper and straighten the blades and also to manufacture other articles from bar steel made under the hammers. The grinding machinery was driven by an 18ft waterwheel, and during the nineteenth century a horizontal steam engine was added to provide power during times of water shortage. Adjacent to the grinding shop is the hafting and boring shop, which uses a further waterwheel to drive its machinery. In addition to this unique assemblage of workshops there is a large warehouse (now containing museum exhibits), offices, a row of workmen's cottages, and a manager's house built about the middle of the nineteenth century.

Not until the second half of the nineteenth century was steel made in quantities sufficient, and at prices cheap enough, to replace wrought iron

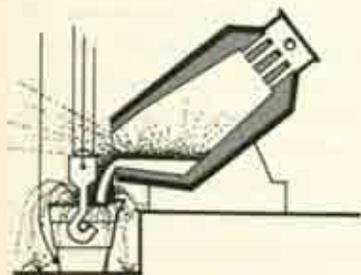
## BESSEMER CONVERTER



1 Charging with molten pig iron



2 Blowing air through the molten iron



3 Pouring out molten steel

Fig 24

for structural purposes, but after the introduction of the Bessemer converter in 1856, less than 15 years elapsed before the new material was beginning to be used extensively, firstly for railway rails and later for boiler plate and shipbuilding. The converter developed by Henry (later Sir Henry) Bessemer (1813-98) was extremely simple in construction and in the essential principles of its operation (Fig 24), being a trunnion-mounted container with a perforated bottom through which air was blown. The converter was first inclined to receive a charge of molten pig iron and then, with air blowing through the bottom, turned upright for air to pass through the iron to oxidise the carbon, silicon and manganese. As heat is given out by this reaction, the temperature of the iron actually increased. The progress of the reaction could be judged by the colour and character of the flames issuing from the mouth of the converter. When the process was completed, the blast was turned down and appropriate additions made to achieve the correct alloy composition. The steel was then poured into a ladle and into ingot moulds. An improvement of the Bessemer process was devised by Robert Mushet (1811-91), the pioneer of modern alloy steels such as high carbon, tungsten and manganese steel. He suggested the addition of manganese to remove the excess oxygen which had previously made Bessemer steel difficult to work.

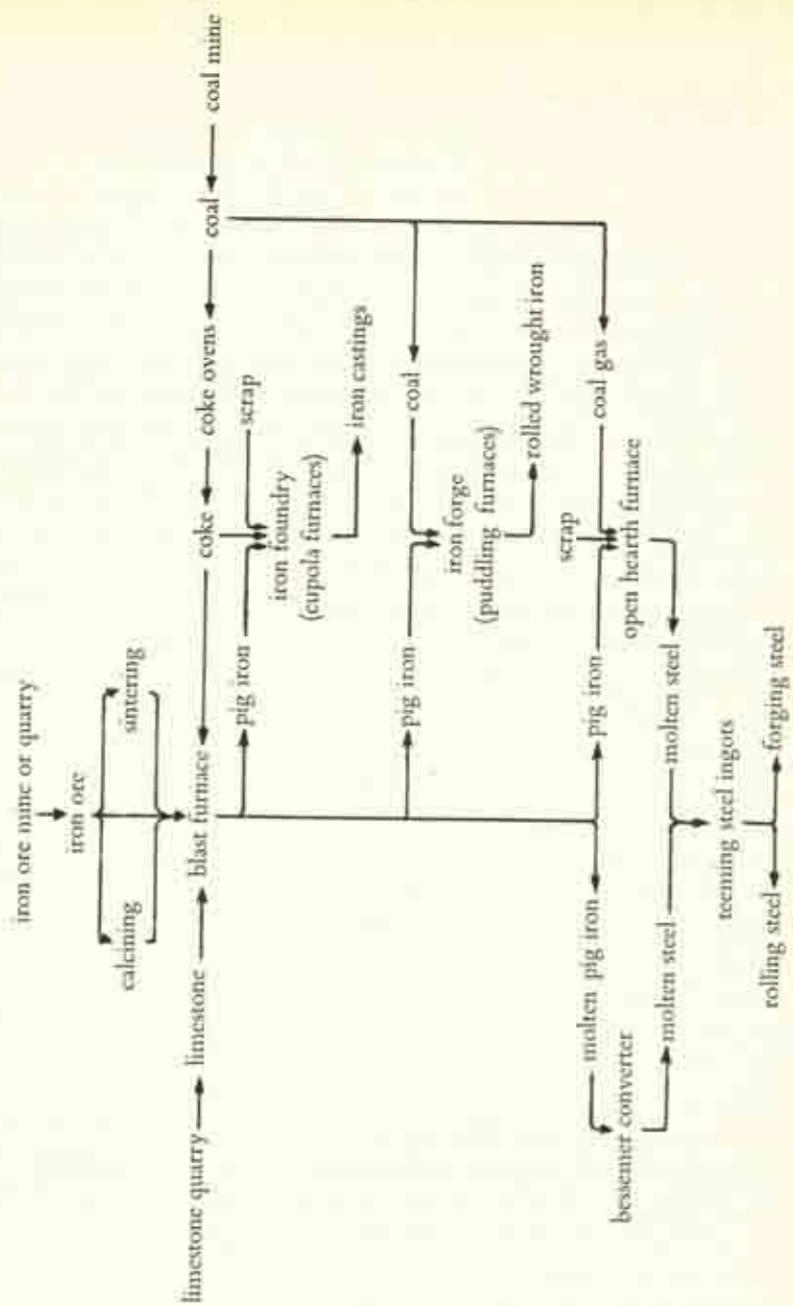
The major disadvantage of the Bessemer process was that it could not remove phosphorus from the pig and, as the phosphorus in the ore accumulates in the iron, only very low phosphorus ores could be used, ruling out many of the chief sources of supply in Britain. The problem was eventually solved in 1879 by Sidney Gilchrist Thomas (1850-85) and his cousin Percy Gilchrist (1851-1935). It was known that lime would react with phosphorus to give calcium phosphate and so remove the phosphorus from the iron but, unfortunately, lime attacked the firebrick lining of the Bessemer converter. This problem was overcome by substitution of calcined dolomite bonded with fireclay as a lining for the converter. This new process was known as the 'basic' Bessemer process (because a chemically basic lining was used) to distinguish it from the original 'acid' Bessemer process. The terms 'acid' and 'basic' are still used for modern furnaces and refer still to the nature of the refractory lining.

The final major development in steelmaking technology during the nineteenth century occurred in the 1860s when C. W. (later Sir William) Siemens (1823-83), a German who became a naturalised British subject,

introduced the regenerative open hearth furnace for converting pig iron into steel, using ore to assist in oxidising the excess carbon and other impurities. The furnace was in some ways similar to the puddling furnace, with flames being directed across the hearth, but the hot gas passes through checker brick regenerators before going up the chimney. The direction of combustion air and gas flow was reversed at intervals so that the incoming combustion air and producer gas were heated in the regenerator before being mixed and burnt in the hearth. Cold or molten pig iron, scrap or a mixture of all these could be charged into the open hearth furnace, which flexibility, together with its greater capacity, led to its gradually superseding the Bessemer converter. Later oil fuel replaced producer gas.

Throughout the whole period of the evolution of iron and steel making techniques the fundamental principles have been those of achieving reduction and oxidation, carburisation and decarburisation, and they apply today as strongly as they did for the Wealden Ironmasters of 4 centuries ago. For nearly 200 years, from the beginning of the eighteenth century until the 1870s, almost every new stage of development occurred in Britain, which by the early nineteenth century had achieved a degree of supremacy over all others in the field quite unprecedented and unrepeatable. The technological innovations of that period, besides giving Britain this commanding world position, had important effects inside the country by creating new regional concentrations of industry. Thus Darby and Cort transferred the iron industry to the coalfields, while Neilsen influenced the establishment of the industry in Scotland. Much British innovation assisted competitors too, so that by the end of the nineteenth century the output of the German iron and steel industry had surpassed that of Britain, helped to a great extent by the use of the Gilchrist and Thomas process for converting the rich phosphoric ores of Lorraine. The archaeology of the iron industry is therefore the archaeology of one of the most important aspects of Britain's past, of a period and of a range of technological processes fundamental in the growth of industrialisation throughout the world.

# PRINCIPAL STAGES IN THE EARLY MANUFACTURE OF IRON AND STEEL



## 7 Engineering

THE Industrial Revolution was to a great extent a revolution in the techniques of making things, a revolution in methods of shaping wood and metal to produce machines which themselves were used to carry out other processes. There were, in effect, two stages in machine making, indeed two types of machine, which might be regarded as primary and secondary. The steam engine, as developed by Newcomen and later Watt, was a primary machine designed to carry out a specific function—initially the driving of a pump to lift water out of a mine. The limits on the efficiency of this primeval steam engine were twofold: firstly the theoretical concept which provided the basis for its design, and secondly, but at least as important, the practical limitations of available technology that applied to the way in which its components were made and assembled.

Early steam-engine making was the province of the millwright whose skills, developed over centuries in the building of windmills and watermills, were the most appropriate ones available. A Newcomen engine, built into a brick or masonry engine-house, using a massive timber beam as the link between steam cylinder and pump rods, was, generally speaking, within the already existing capacities of the millwright. The cylinder, and perhaps the boiler, were the parts of the engine that demanded the most of available technology. As the theoretical concept on which the steam engine was based became more sophisticated, so the demands on technology grew, and so too did the proportion of the total inefficiency of the engine which derived from the way in which it was built. Thus in 1774 when John Wilkinson (1728–1808), the celebrated ironmaster, patented his boring mill, initially used for guns but soon after for steam engine cylinders, he was making a major contribution to the efficiency of the steam engine. Up to this time an engine cylinder had been cast in brass or iron and its bore smoothed by a man rubbing it with rags and sand or by running the roughly cast barrel on a trolley over a boring head mounted on a rotating pole. Any irregularities in the cast bore were inevitably reflected in the finished section, as the flexibility of the pole allowed the cutter head to follow the path of least

resistance. By mounting a cutter on a rotating bar which had bearings at each end, and devising a means of moving the cutter head along the bar, Wilkinson was able to bore a perfectly cylindrical barrel in the casting, which was bolted firmly to the bed of the machine. This boring mill was at least as important in the development of the steam engine as any of Watt's specific and recognised improvements; indeed the double-acting engine, depending as it did on a closed cylinder with a stuffing box around the piston rod, could not have been made without an accurately machined bore, and *that* could only be achieved on a boring mill.

Wilkinson's boring mill falls into the category of a secondary machine—one used to make other machines. It was also what would now be called a machine tool. The evolution of the machine tool was fundamental to the development of better and more efficient machines, and the men who built and used them were engineers rather than millwrights. In engineering a machine tool is a mechanical device concerned with the removal of metal or wood by turning, drilling, boring, milling, planing, shaping and grinding. During the nineteenth century machines were developed to carry out all these processes, sometimes automatically, that is, they could produce a complex sequence of cutting actions using information built into them rather than fed into them by a human operator. This growth of automatic machines and machine tools provided the basis for much of present-day manufacturing industry, saving not just on the numbers of men necessary to carry out a particular process but, much more important, saving on the number of *skilled* men required. The large-scale growth of manufacturing using automatic or semi-automatic tools was a phenomenon initially peculiar to the United States, where there was a great shortage of skilled manpower. It is no accident that the processes developed initially in the manufacture of small arms, which were to culminate in the introduction of production lines for making sewing machines, typewriters and motor cars, should occur first in the United States. The benefits in terms of cheap mass production were obvious, and already industrialised European countries, including Britain, took up these ideas enthusiastically. It is arguable whether these techniques were truly applicable in the context of a British labour force in view of the degradation of skill which they imply, and the first moves away from a production line system where each operative carries out a repetitive but unskilled task to a 'workshop' type of production en-

vironment are now being made, notably in Sweden and Holland.

The engineers who developed the first generation of machine tools during the eighteenth and nineteenth centuries were, in a very real sense, paving the way for the massive scales of production that we take for granted today, and the social and economic implications resulting from their innovations are at least as far-reaching as those deriving from other better recognised aspects of technological advance pioneered in the Industrial Revolution period. The machines they produced enabled other machines to be made more efficient, they enabled them to be made in quantity by making possible the large-scale production of identical components, and in doing *this* they were instrumental in establishing sets of engineering standards, relating to screw threads, for example, which allowed interchangeability of parts between one machine and another.

It is specifically with machine and production tools that this chapter is concerned; unfortunately they represent a much more difficult area of study for the industrial archaeologist than, for example, steam engines, canals or railways, not only because tools such as these were used in factories and workshops where they are often inaccessible but because they became obsolete relatively quickly and were easily scrapped. Many of the best examples of machine tools can now be found only in museums, while production equipment, which is generally very poorly documented, has tended to disappear almost completely. An added problem which applies particularly to production machinery of the last 80-90 years is its often highly sophisticated nature. Thus, appreciation of the significance of a particular machine is confined within the industry where it has been used; if there is no will to preserve it there, it is unlikely that any outside interest will have either sufficient knowledge or influence to secure its retention. Museums of technology tend to collect prime movers and easily understood pieces of manufacturing equipment which can be operated or their method of operation simulated in an easily comprehensible way. Rarely do they venture into the fields of complex production machinery, which makes the need for historical awareness in industry itself all the more critical.

As we have seen, machine tools are primarily concerned with cutting metal, taking on the processes previously carried out laboriously and imperfectly by a craftsman using hand tools. The earliest machine tools were the bow drill and the lathe. In the former a simple drilling bit was rotated

by means of a string wrapped around the spindle of the drill and with each end fastened to the ends of a bow. Rapid oscillation of the bow resulted in a high speed backwards and forwards rotation being applied to the drill bit. In the early lathes rotation was provided in a similar manner, a string or cord wrapped round the workpiece being held by a bow or, more frequently, connected to a treadle beneath the lathe and a springy pole above. The advantage with the pole lathe was that the operator was left free to use both hands to hold the cutting tool against the work. String-operated drills and lathes are of pre-Christian origin and have been used until surprisingly recently in Britain. Bow lathes were used in watch and watch-case making workshops in the Clerkenwell area of London at least until 1970, and examples may be seen in a reconstruction of one of these shops in Liverpool Museum. Similarly the larger pole lathe in its most primitive form was the standard equipment of the chairmakers or bodgers active in the beech woods of Buckinghamshire around High Wycombe.

The first major improvement on the pole lathe came with the introduction of the mandrel lathe in the late sixteenth century. The drive was removed from the workpiece and fixed instead to a mandrel or spindle connected to a live centre which supported and rotated one end of the work, the other end running in a fixed centre. This type of drive also made possible the chuck in which work unsuitable for turning between centres could be held. By the early eighteenth century the mandrel, made of iron, was running in bearings cast of lead-tin alloy, although the frame of all but the smallest watch and instrument makers' lathes was still made of wood. Later in the century screw threads could be generated on a mandrel lathe in which both mandrel and workpiece were moved laterally across the cutting tool held stationary on the toolrest by the operator. A guide screw on the mandrel itself was engaged by a fixed key to drive the mandrel forward at a constant rate. To enable screwcutting to be carried out, an alternative to the intermittent drive afforded by a pole or bow had to be found, and two forms were applied to the mandrel lathe. The most common was a treadle-operated crank connected to a large flywheel which was grooved to take a drive cord, the advantage being that the operator could run the lathe himself. For larger lathes, however, such as those used by wheelwrights for turning wagon-wheel hubs, a separate drive wheel turned by one or even two boys was used.

The primitive screwcutting made possible by moving the mandrel and

workpiece was greatly improved upon about 1770 by Jesse Ramsden (1735–1800), an instrument maker. The basis of Ramsden's lathe was to mount the cutting tool, ground to the profile of the thread, in a slide rest and propel it along the workpiece by means of a lead screw connected to the mandrel by a series of gear wheels. The number of threads per inch depended on the rates of the gears connecting the mandrel to the leadscrew and on the number of threads on the leadscrew itself. The first large-scale practical application of the screwcutting lathe resulted from the work of Henry Maudslay (1771–1831), an engineer who was to have a profound effect on the development of precision engineering and an overwhelming influence over his own and the succeeding generation of mechanical engineers. Indeed, much of the evolution of machine tools can be traced through the personal connections forged between Maudslay and his own employer Joseph Bramah (1748–1814) and those who subsequently worked for Maudslay Sons & Field, the firm he established in London. Born in Woolwich and employed in various workshops of the Arsenal from the age of twelve, Henry Maudslay rapidly gained a reputation for skill as a metalworker, a reputation which about 1790 gained him a position in the workshop of Joseph Bramah, already well established as a maker of permutation locks that, in improved form, are still made today. The influence which this brilliant Yorkshire inventor had on the young Maudslay must have been enormous, and the benefits which Bramah himself was later to derive from the ideas sparked off by his pupil represent a classic example of the cross-fertilisation on which much inventive genius was based. Bramah, besides inventing the lock on which most of his fame rested, also patented a rotary pump, and developed a highly successful hydraulic press, a beer pump and a machine for consecutively numbering banknotes which enabled the Bank of England to dismiss 100 clerks! His interest in hydraulics—as early as the 1770s he had designed a successful water closet which was standard for a century—led him to propose the transmission of hydraulic power from central generating stations by means of mains pipes under the streets to which customers could be connected, an idea later taken up in almost every large port in the country.

In this atmosphere of ideas Maudslay thrived and, probably jointly with Bramah, developed his screwcutting lathe. This comprised a slide rest mounted on a bed of two triangular-section bars, and a headstock carrying the live spindle or mandrel which was connected to the leadscrew by a pair

of gears. This leadscrew drove the slide rest, referred to for many years as 'Maudslay's Carriage', on which the tool was clamped. The lathe was equipped with several leadscrews having different numbers of threads per inch so that screws of different pitch could be generated. By 1800 Maudslay had conceived the idea of using change wheels to avoid the need for alternative leadscrews. His screwcutting lathe of 1800, on view in the Science Museum, London, has twenty-eight change wheels, giving a range of 16 to 100 threads per inch.

After the introduction of the slide rest by Maudslay subsequent improvements in the lathe included the development by one of his pupils, Richard Roberts (1789-1864), of the four-step pulley and back gear which gave eight spindle speeds, and the self-acting traverse which enabled the tool to pass smoothly and automatically along the workpiece, driven by a long screw additional to the leadscrew and driven from the main spindle by a type of bevel gearing. Perhaps the most radical improvements, however, came as the result of American inventions, starting in the 1840s with the turret lathe in which a clamp holding as many as eight tools could be rotated to bring any one of them to bear on the workpiece by the simple operation of a locking lever. This was followed in 1873 by the automatic lathe, introduced by Christopher Spencer (1833-1922), in which movement of the cutting tools and turret was controlled by adjustable cams known as 'brain wheels'. The machine could be fed with bar stock and automatically manufactured components such as screws. A British automatic screw machine, patented by C. W. Parker in 1879, is in the collection of the Science Museum, London, while a similar machine is operated from time to time in the Birmingham Museum of Science and Industry. Other American contributions to lathe development in the late nineteenth century included the multi-spindle automatic lathe, in which a number of components could be made simultaneously, and the Norton quick-change gearbox, which eliminated the need to slip the drive belt from one pulley to another to change speed. At about the same time the introduction of high-speed steel for cutting tools greatly increased the productivity of the lathe and other machine tools and, because of the greater feed rates which were possible, resulted in much heavier and stiffer methods of construction.

To return to Henry Maudslay, his further contributions to the development of engineering and of machine tools were not concerned only with



31 Saw at Portsmouth naval dockyard for cutting lignum vitae. Installed in 1804 as part of Sir Marc Brunel's set of blockmaking machines

lathes but with standardisation and automatic machine tools, and in their own way anticipated American inventions by half a century. His table engine of 1807 was an example of a steam engine designed for standardised factory production and great portability, the first such engine to be produced in large numbers and the first widely available form of small steam power unit for factories that did not necessitate the complex installation procedures demanded by the house-built beam engine. Maudslay also pioneered the use of the surface plate as a contribution to accurate work by his employees, a carefully ground slab of cast iron being on every man's bench.

Far and away his most advanced pieces of work, however, were the forty-four machines he made to the designs of Marc Isambard Brunel

(1769-1849) for manufacturing pulley-blocks for the Royal Navy. At the instigation of Sir Samuel Bentham (1757-1831), Inspector General of Naval Works, Brunel was commissioned in 1801 to design equipment (Plate 31) capable of producing at least 100,000 blocks per year at a critical period in the war with Napoleonic France. The machines, designed by Brunel, were built by Maudslay, who doubtless contributed to their design. By 1808 the plant was in operation at Portsmouth, perhaps the first installation in the world in which machine tools were used for mass production. Output per year was 130,000 blocks, produced by ten unskilled men doing the work of 110 skilled men and saving the Admiralty £17,000 per annum for a capital outlay of £54,000. Driven by line-shafting from a 30 hp steam engine, the machines carried out the whole carefully programmed sequence of operations from sawing sections from elm logs, through the stages of mortising and drilling and turning the *lignum vitae* sheaves, to recessing for the metal bushes. Many of the machines remained in use for 145 years and several are preserved *in situ* in Portsmouth dockyard. Eight others are on view in the Science Museum, South Kensington. The Portsmouth blockmaking machinery established Maudslay's reputation beyond doubt, brought him a most valuable collaborator in the person of Joshua Field (1786-1863), a dockyard draughtsman who eventually became his partner, and, perhaps more important in terms of the long-term development of machine tools, made his firm the focal point for any aspiring young engineer anxious to train in an atmosphere of invention and innovation.

The most eminent of the engineers who worked for Maudslay were Richard Roberts (1789-1864), James Nasmyth (1808-90) and Sir Joseph Whitworth (1803-87). Roberts, as we have seen, made important contributions to lathe design but he was also responsible for making the spinning mule self-acting and for inventing a device for punching rivet holes in wrought-iron plate at exact intervals, in response to a request in 1847 from the builders of the great tubular girder bridges at Menai and Conway.

James Nasmyth was born in Edinburgh, son of a landscape artist and engineer. His early interest in ironmaking, brassfounding and engineering led him at the age of 21 to visit Maudslay at his Lambeth works, where he was taken on as an assistant, a position he held until shortly after Maudslay's death in February 1831. He set up on his own account at Edinburgh later that year and then moved to a small factory in Manchester. As his business

expanded, he needed more space and took a 6 acre site at Patricroft, west of Manchester, bounded by the Bridgewater Canal, the Liverpool & Manchester Railway and a good road. There his engineering works grew up. In 1836 he invented the shaper, in which a piece of metal secured to a table is cut by a tool clamped to a horizontal ram that moves backwards and forwards over the workpiece, which in turn is traversed by a screw drive, either hand-operated or driven from the main shaft. Nasmyth's shaper in basic form is still used today, although there have been detail improvements. It is particularly suitable for planing small surfaces, cutting key-ways or producing any face which can be formed of straight-line elements. Nasmyth's most celebrated invention was the steam hammer, devised in response to the need for a 30in diameter paddle shaft for Brunel's *Great Britain* steamship. In the event the *Great Britain* was built with a screw propeller and Nasmyth's design of 1839 was not implemented until 2 years later. The only forging hammers available previously had been the water-powered tilt or trip hammers (Fig 22) which were severely limited in that they could only be lifted a relatively small height, and the force of their blows under gravity was not great nor could they be controlled. Nasmyth's hammer consisted simply of a vertically mounted steam cylinder supported on a type of A-frame with a hammer head fastened to the end of the piston rod projecting through the bottom of the cylinder. The anvil lay between the legs of the frame. Initially steam was used only to raise the hammer, which then fell under its own weight, when the steam was allowed to escape, but later versions were double-acting, the steam being applied above the piston to produce a more powerful and controllable blow. Later steam hammers, particularly those for fairly intricate forging work, had only one supporting pillar (Fig 25). There is a steam hammer of this latter type in the Underfall Yard workshops of the Port of Bristol Authority (156/ST 572722), while two large A-frame hammers, one of which is still in regular use, are involved in the wrought-iron puddling process still carried on at Walmsley's Atlas Forge in Bolton (101/SD 713084). Eccles Museum contains a wealth of information on James Nasmyth.

The third of Maudslay's eminent employees to make a name for himself in the machine tool field was Joseph Whitworth, a Mancunian who at the age of 22 left his work as a mechanic to come to London. In 1833 he rented a workshop in Manchester and set up as a toolmaker. By the Great Exhibi-

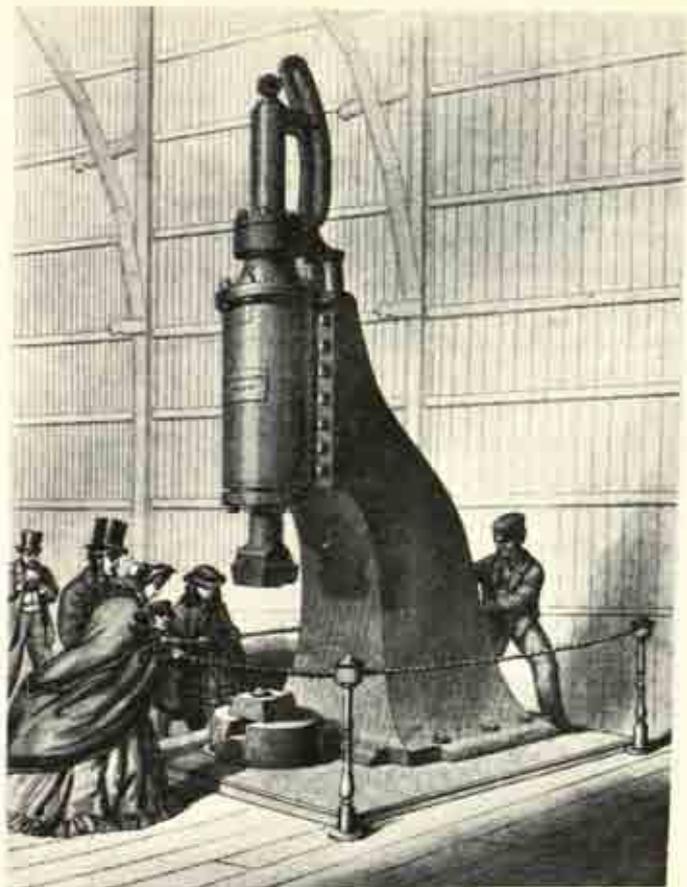


Fig 25 Morrison's patent double-acting steam hammer (from *The Circle of the Sciences*, Vol I, 882)

tion of 1851 this most prolific of all the machine tool manufacturers was able to exhibit twenty-three separate machines, in contrast to the two or three of most other makers, and by the 1862 Exhibition one quarter of the total space allotted to machine tools was occupied by Whitworth, the remainder containing the products of more than sixty other firms.

Whitworth was not so much an inventor of completely new tools or techniques as an improver of existing ones, and his work was based on the meticulous standards of precision which his years with Maudslay Sons &

Field had inculcated in him and an ability to experiment in a relentless and thorough manner. His initial improvements were made to lathes, and his patent of 1839 covered a split-nut which enabled the leadscrew to be engaged and disengaged at will. He also introduced the hollow box casting for lathe beds which was much more rigid than the triangular bars used by Maudslay and afforded good protection to the leadscrews. He produced a highly efficient planing machine based on previous designs by Richard Roberts and Joseph Clement (1779-1844), both Maudslay protégés, but whereas these early machines were hand-operated, Whitworth's was both power-driven and self-acting. In his 1842 machine the workpiece was clamped on a table which ran back and forth in a horizontal plane while a cutting tool mounted above it traversed the work a step at each stroke. His earliest design had a quick-return mechanism to make maximum use of the total operating time for cutting, but in the 1842 model the tool was mounted in a swivelling box that enabled it to be reversed at each stroke and cut the workpiece in both directions of travel.

Another area in which Whitworth's powers of pragmatically inspired improvement were put to good effect was in the development of precision measuring equipment, and here again the debt he owed to Maudslay is self-evident. In 1841 at the Institution of Civil Engineers Whitworth was advocating 'the general use of standard gauges, graduated to a fixed scale, as constant measures of size', which he pointed out would enable standard machine parts to be produced. Maudslay had already produced a bench micrometer, taking advantage of his knowledge of accurate screw-thread cutting and Whitworth developed this idea further and to greater degrees of accuracy, demonstrating in 1851 an instrument capable of measuring one-millionth of an inch.

Perhaps the most famous example of Whitworth's work was his standardisation of screw threads, which resulted from his famous paper *On a Uniform System of Screw Threads*, read in 1841. At this date the design of screws was chaotic, with no common formula for proportioning the number of threads per inch to their diameter. Whitworth's answer to the problem was characteristic, highly practical and overwhelmingly successful. Making an extensive collection of screw-bolts, as he described them, from numerous engineering works, he analysed their various characteristics in terms of pitch (the number of threads per inch), depth (the amplitude of the

thread), and form (the shape of the thread). These he related to various diameters to discover maximum strength and durability. The depth of the thread in the various specimens he examined varied more than did the pitch, and the angle made by the sides of the thread was taken as an expression for the depth. The mean of the angle in the tin diameter screws was found to be about 55 degrees, which was also nearly the mean in the remaining screws of all diameters which were examined. This angle he then adopted as his standard and in doing so a constant proportion was established between depth and pitch. The 'Whitworth' threads which resulted from this exhaustive survey were quickly and widely accepted and became the main threads used for engineering work in Britain until 1905, when the British Standard Fine Thread was introduced to cater for the need for finer pitches. The Whitworth, or BSW, thread continued in use alongside the BSF and small BA (British Association) threads as standard until 1949, when a new thread, the Unified Screw Thread, was introduced under BS 1580. Since then something of a return to the pre-Whitworth shambles has occurred, with a whole variety of Unified threads, of American origin, themselves being superseded by the Metric threads advocated by the International Standards Organisation. In addition numerous variations occur in the sizes and depths of hexagons for bolt heads and nuts.

There is no doubt that detailed analysis of screw threads and of wood-screw design can provide the industrial archaeologist with valuable dating evidence as, despite the introduction of standard types, there is enough variation in thread design, bolt head and nut shape and size, and materials used (iron or various types of steel), to enable reasonably accurate chronologies, if not absolute dates, to be worked out. Hand chased or leadscrew threads cut on a lathe can be differentiated from threads cut by tap or die, while the changeover from square bolt heads and nuts to hexagons deserves detailed examination. The use of coach bolts with domed heads of various sizes is yet another area of study. The wood screw, too, has been through numerous stages of development. Other types of specialised threads also had their standards, Whitworth's own work extending to cover pipe threads and spanners, as well as wire gauges.

Another important machine tool of the mid-nineteenth century was the milling machine. Milling is the removal of metal from a workpiece by passing it beneath or across a rotary cutting tool, in contrast to shaping or

planing, where the tool is fixed. The concept of milling was certainly understood by the French clockmakers of the eighteenth century, who used small milling machines to cut gear wheels, but the credit for developing the miller as a commercial machine tool goes to a group of American engineer inventors of whom Eli Whitney (1765-1825) was the first and most important. In 1818 he made a small milling machine. This had a power-driven table, to carry the workpiece, moving horizontally below the cutter spindle and at right-angles to it. It was not until 1848, however, that a milling machine was manufactured for sale, designed by F. W. Howe (1822-91) for the Robbins & Lawrence Company of Vermont. This was followed in 1855 by the Lincoln miller, of which thousands were sold throughout the world. The problem of machining the helical flutes in twist drills, which began to replace the older flat drills during the 1850s and 1860s, inspired further refinements to the milling machine, the answer being found in 1862 by Joseph Brown of the Brown & Sharpe Company of Providence, Rhode Island. The machine he produced embodied all the basic features of the milling machine as we know it today, and with these features it deserved to be called a universal miller. Vertical adjustment of the workpiece using a screw-operated knee sliding in vertical guides, a spiral head geared to the feed mechanism to enable spirals to be cut, and provision for machining tapered spirals (necessary to make tapered reamers) were all included. Five of the original Number 1 model of Brown's miller were sold in Britain, and one is preserved in the Machine Tool Collection at the South Kensington Science Museum.

One further important machining process has still to be considered—the shaping of metals under abrasive stones, both natural and artificial. The development of the grinding machine was again largely the work of American engineers, although Nasmyth produced a grinder in 1845 with two 7ft diameter cast-iron wheels on which the abrasive stones were mounted. The introduction of artificial grindstones in the 1850s consisting of iron oxide, aluminium oxide or silica grits (emery), bonded with clay or rubber, accelerated the development of the grinder, which culminated in the introduction of a universal machine by Brown & Sharpe in 1876 in which most of the features of modern grinders were incorporated. The durability and cutting power of grinding wheels was greatly improved with the invention by E. A. Acheson in 1891 of carborundum, the name he gave to

artificially produced silicon carbide. By the early 1900s grinding had become a well established technique for removing metal and sharpening cutting tools.

The failure after about 1870 of the British engineering industry to initiate major innovations in the design and manufacture of machine tools, textile machinery and production equipment is highly significant and marks a distinct terminal point in the hitherto steady progress of industrial growth. Some might say it marked the end of Britain's Industrial Revolution based on new ideas; from the end of the nineteenth century the United States and Germany took the lead in innovation in the manufacturing field. The industrial prosperity of this period in Britain was based on the techniques and skills, tools and equipment that had been used in the previous generation. Markets were easy to find and the incentive to devise new means of doing things had consequently diminished. But a completely new form of engineering industry was developing in the United States, an industry geared up to the production of large numbers of identical, relatively small, components, finished to fine tolerances on machines that required little skill from the operator. The significance of this quickly becomes apparent to the industrial archaeologist working in Britain. Firstly he finds machine tools of surprisingly obsolete design dating from the latter part of the nineteenth century. The Port of Bristol Authority's Underfall Yard workshop is an example with an almost complete range of machine tools of the mid-1880s, mainly of Manchester origin and still in occasional use. But an examination of the smaller precision mechanisms commonly in use in Britain reveals a different state of affairs. American sewing machines, typewriters, wall clocks and gramophones and German mechanical toys were finding their way into homes and offices. They were made by what came to be called 'The American System' of mass production. Brown & Sharpe micrometers, the ingenious pin tumbler cylinder locks invented by Linus Yale, Jnr, in 1865, and even American agricultural equipment can all be found without difficulty in this country. Eventually the change in approach came in Britain, a change accelerated by the technological demands of two world wars, but not before the demise of much of what the old order stood for. As Henry Ford launched into his 15 million Model 'T' motor cars, firms like Maudslay Sons & Field and James Watt & Company closed their doors for the last time.

## 8 Non-ferrous Metals

A NUMBER of non-ferrous metals were of increasing importance during the eighteenth and nineteenth centuries. Some, such as copper, tin and lead, had been known since antiquity, but others, of which zinc was the most important, were in effect 'new metals' from the point of view of their large-scale industrial application. All these metals were available in Britain, and the industries of mining or quarrying their ores, or in some cases the native metal itself, frequently enjoyed phenomenal rates of growth and prosperity. Just as often this was followed by total collapse, as deposits were worked out or cheaper foreign ores began to reach Britain in large quantities in the latter part of the nineteenth century. Of the four most important metals already mentioned, and of the less prolific deposits of gold and silver, only tin is mined in Britain today. This relict tin industry, however, with its two surviving mines, at South Crofty (189/SW 669409) and Geevor (189/SW 375345) in Cornwall, may form the basis for new expansion in the future as the high cost of overseas metal forces prospectors to look once again at the traditional sources of supply. A third mine may be opened in the Truro area. Samples from a shaft sunk west of Wheal Jane are being checked.

The requirements of industrialisation both expanded traditional demands for non-ferrous metals and created new ones. Thus copper, which had been used for coinage both in its pure state and alloyed with tin in the form of bronze, was needed for sheathing the hulls of wooden sailing ships and, of much greater importance, as a component with zinc for the alloy brass. The unprecedented demand for brass created by the growth of the Birmingham metal trades and engine and machine builders led to an enormous expansion in copper mining, quarrying and smelting in the late eighteenth and early nineteenth centuries. Thus copper production rose from about 2,000 tons per annum in 1700 to more than 7,000 tons by the end of the century. Similarly tin, used initially for making bronze, bell metal and solder, came into its own with the growth of the tinplate industry in the early years of the nineteenth century. The expansion of the lead industry, which occurred mainly in the middle of the nineteenth century, was not as rapid, but, like the others, it too eventually fell into decline.

Like iron and steel, the non-ferrous metal industries consist of three basic divisions—the mining of the ore, the conversion of that ore, using a fuel, to produce a refined metal, and the use of the metal to make a finished product. As with iron and steel, developments in technology and the economics of transport resulted in the various refining processes of the industry changing their location. Lead, tin and copper were already being smelted and refined, using mineral fuel, in reverberatory furnaces before the Industrial Revolution period, and, as the industry expanded, there was a growing tendency towards coalfield locations for smelting works. In the 1720s copper smelting was being transferred from sites near the copper mines in Cornwall to Swansea because coal was half the price in Wales, and in the smelting process much more fuel than ore was consumed. The technicalities of smelting also required that ore from different sources be mixed, an additional incentive to coalfield-located sites. As the main non-ferrous ores, unlike many of the iron ore deposits, tended to be located away from coal, considerable transport costs resulted, whichever way the system was worked. Thus Anglesey copper was generally smelted on the Lancashire coalfield, notably at St Helens, but some went as far afield as South Wales. By 1750 over half the total output of British copper was being smelted near Swansea, and it was a similar story with lead. Highly integrated organisations grew up, with partnerships having control of all stages of the process—the ore mining in one area, smelting and perhaps colliery owning in South Wales, and sometimes an interest in a rolling mill or metal manufactory in Birmingham. Thus the whole industry was being controlled by capitalists who had a national point of view and could balance the various components of the production process to determine the most satisfactory locations for their plant and to know which ore sources were profitable to work and which were not.

#### COPPER AND ZINC

Copper was perhaps the earliest metal known to Man, although it was not until it was alloyed with tin to form bronze hard enough for tools and weapons that it became widely used. In the Britain of the Industrial Revolution copper continued to be employed in its traditional role, for making bronze for a variety of purposes, but it was the widespread demand for brass, an alloy of copper and zinc, which resulted in the rapid growth of the

industry, and for this reason it is worth considering the two metals together. There were a number of areas where copper occurred in workable quantities, of which parts of Cornwall and Devon, Anglesey and the Lake District were the most important. The ore is generally found in the form of a sulphide requiring a number of processes to convert it into metal. As many as fourteen separate stages were involved but this became simplified to about six during the early nineteenth century as the Webb process became universal. The ore was first roasted and then melted in furnaces with 'metal slag', a by-product from later stages in the process. This gave 'coarse metal' containing some 35 per cent copper, which was granulated by running it into a pit filled with water. The granulated coarse metal was then calcined (roasted) and subsequently melted with slag or ores rich in copper oxide. This resulted in metal containing about 75 per cent copper and 'metal slag'. The copper was run out of the furnace to make pigs which were transferred to a melting furnace and heated under vigorous air flow. The products of this stage were 'blister copper', about 95 per cent pure, and 'roaster slag'. The blister copper was tapped into sand moulds and further refined in a remelting furnace, where it was allowed to oxidise. The slag was skimmed off and the molten metal had charcoal or anthracite stirred into it with a green wood pole of birch or oak. This resulted in the copper seething as the gases were given off by the wood and becoming exposed to the deoxidising action of the charcoal or anthracite. All these various stages tended to concentrate the impurities in the slag, which was then removed, the final product being very pure copper. Purity was essential, any contaminants seriously impairing the mechanical properties of the metal. Thus even 0.2 per cent of oxygen in the finished copper resulted in brittleness.

Remains of the copper ore extraction industry are numerous although the various refining processes have left little in the way of tangible and comprehensible evidence on the ground. The Swansea valley on the other hand, perhaps one of Britain's most devastated industrial areas, shows what can result from unbridled development and subsequent decline of industries which produce large quantities of toxic or totally sterile by-products. The mining of copper in Britain on a large scale became established through the agency of a government-backed monopoly, The Society of Mines Royal, incorporated in 1568. With twenty-four shareholders, ten of whom were German, and between 300 and 400 German miners, the first workings

were started near Keswick in Cumberland. The Crown received one-fifteenth of all copper produced and 10 per cent of any gold or silver. The only very early site identifiable as one worked by the Mines Royal is Goldscope Mine, Derwentwater, although most of the remains are probably of early nineteenth century date. An adit is visible (82/NY 228186) and there are shafts nearby (82/NY 226187). Over a mile of passages extend beneath Scope End, but these may well have been connected with lead mining as well as copper. Elsewhere in the Lake District more substantial remains can be seen not only of the mines themselves but of the plant used to concentrate the ore before it was taken for smelting. Like so many of these early metal mines, the sites are often highly dangerous, with small shafts often completely hidden in undergrowth. Very great caution must be exercised in exploring these areas. Underground workings should *never* be explored except with a local expert in charge.

Perhaps the most rewarding copper mine area is the valley of the Red Dell Beck, where the Coniston mines were established by the Mines Royal in 1599. Most of the present-day traces, however, are of nineteenth-century origin, dating from after 1834. The present youth hostel (88/SID 289986) is in the centre of the crushing and stamping works area, with the main workings away to the north-west. There are numerous adits, shafts and piles of slag, the remains of smelting carried out at the Low Mill site, 200 yd south of the hostel, in the 1890s. Initially the ore was picked over by hand, but by the middle of the nineteenth century mechanical 'jiggers' were being used to sort the grades of ore and there were various types of 'buddle' or separator. Even so, ore processing was a labour-intensive activity and some 600 people were employed, including a number of women and children, when the works was at its peak. Fortunately, water power was available in abundance and there were thirteen waterwheels in use in the 1850s. Before the railway reached Coniston in 1859, about 250 tons of ore a month were carried away to be sent out by ship from Greenodd (88/SID 315826), then the major port in the area. Subsequently ore was carried to Ulverston by rail. Decline set in soon after the great Rio Tinto mines started large-scale production in 1873, and with further competition from Chile developing after 1882, Coniston copper mining, like copper mining throughout Britain, soon came to an end. Other remains in the general area include the foundations of crushing houses, wheelpits, and settling beds at Tilberthwaite (88/NY 306007) built

in the 1850s and 1860s.

Although the Mines Royal had interests there in the 1580s, copper mining on a large scale did not begin in Cornwall until the seventeenth century, the ores being shipped in increasing quantities from the 1690s to Bristol, Neath and Swansea although smaller quantities were smelted near the mines. Between 1700 and 1870 copper was of overwhelming importance in the Cornish economy, reaching a maximum output in the 1860s of 140,000 tons of ore per annum, to be followed by a steady decline as the workings became exhausted and cheaper foreign ores came into the country. Huge fortunes were made out of Cornish copper, both at the mining end of the industry and in the smelting works of Swansea where Cornish entrepreneurs had a large financial stake. There was one major attempt at smelting ore in Cornwall, however, at Hayle, and although the smelting and rolling plant has now gone, the area of Copperhouse (189/SW 568380) has canal dock walls built from copper slag or 'scoria' blocks 18in x 12in x 8in, which were provided free to the company's employees if they wished to build their own houses. Starting in the 1750s, the Cornish Copper Company's activities at Hayle lasted into the second decade of the nineteenth century, but the idea of smelting in Cornwall was basically unsound, some three to four times its own weight in coal being needed to smelt the copper ore and there being no local coalfield.

The archaeological evidence of copper mining in Cornwall is somewhat confusing, as many mines produced tin as well. The major areas of copper production are clearly defined, however, and included those of Redruth and Chacewater, another west and south-west of Redruth, the Marazion district, the Levant and Botallack mines north of St Just on the Land's End peninsula, the Porthtowan and St Agnes area and along the coast near St Austell north of Sticker. In the east of the county copper was also mined on Caradon Moor, north of Liskeard, and around Gunnislake and Callington. As the archaeology of the copper and tin industries, consisting largely of engine houses, waste tips, remains of crushing and stamping equipment and a few Cornish engines, is so inextricably intermixed, specific sites will be considered in the tin mining section of this chapter.

Perhaps the most spectacular of all the copper mining sites in Britain is Parys Mountain, Anglesey (106/SH 4490), which began as a series of small mines in the late 1760s but developed into a vast opencast quarry after the

collapse of most of the mine workings. By the 1790s Parys Mountain was being systematically cut away by 1,500 men to form the largest copper workings in Europe, while the nearby hamlet and port of Amlwch (106/SH 449934) had grown into a small town from which the ore was shipped to Liverpool, Swansea and Holywell. Inferior ore, overcharged with sulphur, was roasted on the spot, the fumes destroying vegetation for miles around. This, together with the great chiasm of the quarry itself, evoked descriptions of 'the awful spectacle of sublimity', 'the savage grandeur of the scene' and at the same time 'excited the most sublime ideas intermixed with sensations of terror' from all who saw it. By 1815 the balloon had burst, for copper prices had dropped and the best lodes were worked out. Revivals occurred briefly at intervals down to 1883, when mining finally ceased, leaving the lunar landscape of today surmounted by an incongruous windmill tower (106/SH 444906) built in 1878 to assist a steam engine in draining the workings. A diorama of the Parys Mountain workings based on J. C. Ibbetston's late eighteenth-century watercolour may be seen in the National Museum of Wales, Cardiff.

Although zinc ores occur, often in association with lead, in a number of places in Britain, notably in Cumberland, Derbyshire, Durham, Somerset and North Wales, nowhere are they found in abundance, nor are they worked today. The most important ore is calamine, the carbonate of zinc, but the sulphide, known as blende or blackjack, has also been of commercial importance. The primary use for zinc found in Britain was for alloying with copper to make brass, but later, from the 1840s, the process of coating sheet iron or steel with the metal, known as galvanising, became increasingly important. The use of zinc for coating grew still further after the development of rolls for producing corrugated iron sheet at West Bromwich in 1844 and the widespread adoption of galvanised wire for fencing, while the development of electric batteries created a demand for the metal in a pure form as anodes.

Evidence of zinc extraction is sparse and difficult to identify, but in one of the major areas of working in Britain — the Mendip Hills of Somerset — 'gruffy ground', as it is known locally, in the neighbourhood of Shipham and Rowberrow is probably the result of calamine working from the late sixteenth century onwards. A stone chimney some 20ft high in a field across the main street from Shipham parish church (165/ST 445574) could possibly

be the remains of a processing plant where the calamine was calcined. Mendip calamine was used for the manufacture of brass, mainly in Bristol, the port where copper was brought in from Cornwall. It was used for wire making, very important for the carding of wool (see p243); and for sheet brass used in the production of pots and pans known as 'battery ware', the name arising from the fact that the brass was battered under water-powered hammers.

One of the first brass mills in the Bristol area was set up in 1702 by Abraham Darby at Baptist Mills, and when he moved to Coalbrookdale some 6 years later, it continued and expanded under the leadership of the remaining Quaker partners. In the succeeding 30 years more mills were established along the River Avon upstream towards Bath and on several of the tributary streams. Keynsham, the most suitable of these new sites, eventually became the headquarters of the company and was the last place in the Bristol region where brass goods were manufactured, ceasing production in 1927. In the eighteenth century, however, the Avon valley above Bristol was the technical centre of the brass industry and site remains can still be seen. At Keynsham itself are the remains of the brass mill with its weir (156/ST 657688) and at Saltford are the less significant remnants of a smaller site (156/ST 687671). The battery mill here closed in 1908, the last brass battery in the country, but the rolling mills remained, enjoying a brief revival during World War I, to close finally in 1924. Perhaps the most spectacular and archaeologically important site, however, is that north-west of Kelston (156/ST 695680), where the surviving walls and watercourses of a substantial works are dominated by the conical square-section towers of two annealing ovens in which brass battery could be heated to make it malleable again after becoming 'work-hardened' under the hammers.

Another site near Bristol of some importance is the Warmley Works (156/ST 668728) of William Champion, possibly the first place in Europe where metallic zinc or spelter was extracted on a commercial scale. It was established at Warmley about 1740, but had earlier origins in Bristol, where Champion took out a patent for deriving spelter from calamine. This was a breakthrough of some importance, as previously brass had been made by heating metallic copper and calamine together under a layer of powdered charcoal in a crucible. From 40lb of copper and 60lb of calamine (or blende) some 60lb of brass could be produced.



32 Warnley brass works near Bristol. The most substantial relic of William Champion's eighteenth-century works is this stone building incorporating black copper slag blocks

Champion's ability to separate metallic zinc, which was liable to volatilise very readily during the extraction process, led to the manufacture of very fine brass, 'by the direct union of copper and zinc, care being taken to prevent the access of air to the materials while in fusion.' There is little on the Warnley site today which provides evidence of the technical aspects of Champion's activities, but several surviving buildings incorporate black scoria blocks as quoins (Plate 32). The site of the dam which impounded water for the waterwheels can still be traced, while from the dry bed of the millpond protrudes the remains of a seated statue of Neptune constructed entirely of slag blocks! Grottoes and ornamental walks separate the lake from Warnley House where Champion lived. The house is now used as council offices.

Although the brass industry of the Bristol region has become obsolete, with no Cornish copper being brought into the city docks and calamine mining on Mendip extinct, the area has continued to have associations with the production of zinc, which in its pure form was being used in Bristol in

quantity for galvanising flat and corrugated-sheet iron in the middle of the nineteenth century. Today zinc is produced in a modern plant developed at Avonmouth by the Imperial Smelting Corporation, in which a blast furnace is charged with roasted zinc ore concentrates and the vaporised zinc condensed on a continuously circulating stream of molten lead. By feeding lead-zinc concentrates into the furnace, lead also can be recovered.

#### TIN

Tin for alloying with copper to form bronze and with lead to produce pewter and various solders has been mined in Britain, mainly in Cornwall, for over 2,000 years, and tin ore, after iron, has perhaps been the most extensively worked metal-bearing mineral in the country. In the early nineteenth century successful experiments using tin-plated iron sheet to make cans for preserving food led to an enormous demand for tin, and today nearly half the world output of the metal goes into the making of 'tinplate'. Tin, of all metals, is one of the most familiar to everybody, although what is invariably called tin today is in fact tin-plated sheet steel. Tin is highly resistant to corrosion but is expensive and lacks strength. The result of coating a sheet of steel about 0.01in thick with a layer of tin perhaps only 20 millionths of an inch thick is a combination of sterility and strength ideal for food canning.

As was the case with much of the copper from Cornwall, so too the tin mined extensively in the Duchy found its way across the Bristol Channel, to the tinplate works of South Wales. Tinplate making was established there, at Pontypool and Cydweli, in the early eighteenth century and the process continued, but with steel replacing wrought iron, virtually unaltered down to the 1950s. Then the old hand mills finally gave way to modern strip mills, and an electrolytic tinning plant was set up at Ebbw Vale in 1948. A number of buildings used for the manufacture of tinplate can still be seen at Swansea, Pontardulais and Llanelli, for example, but most are now used for other industrial purposes and are of little interest to the industrial archaeologist. The site at Cydweli (152/SN 421079), however, is worthy of examination if only for the plaque on the wall above the door indicating that the works, 'the oldest in the Kingdom', were rebuilt in 1801. Cydweli was in fact preceded by Pontypool, but the site is nevertheless of considerable note and

33 Melingriffith water pump, Glamorgan. Double-beam pump powered by an under-shot waterwheel and used to return water from the River Taff to the Glamorgan Canal



surprisingly complete, with brick buildings and chimneys still standing, many of early nineteenth-century date.

Perhaps the most notable surviving monument of the tinplate industry is the Melingriffith water pump (154/ST 142801). The Melingriffith tinplate works at Whitechurch, some 3 miles north-west of Cardiff, were powered by waterwheels using water from the River Taff, but problems arose as a result of the Glamorganshire Canal Company taking water from the river and causing stoppage of work in dry summers. The final answer, after years of litigation, came when the canal company agreed to take less water from the upper reaches of the Taff and to pay £700 for the manufacture and installation of a water-powered pump (Plate 33) to return water to the canal from

the river below the works. Although in an advanced state of decay, the Melingriffith pump is still sufficiently complete for its method of operation to be made out. An undershot waterwheel drove, by means of two cranks and connecting rods, timber rocking beams that in turn operated the pistons in two cylinders, the water being drawn up alternately in each. The only other large pump of a similar nature in Britain is at Claverton near Bath (166/ST 791644), and that was used for lifting water from the River Avon into the Kennet & Avon Canal (see p77).

Far and away the most spectacular and widespread industrial archaeological remains of the tin industry, however, are in Cornwall, the county which for 2,000 years was Europe's major source of the metal. Reaching its peak in the second half of the nineteenth century, Cornish tin mining then began to feel the effects of overseas imports, mainly from Malaysia, and today, with the exception of the two sites mentioned at the beginning of this chapter, the mining industry is extinct. The legacy which tin mining has left the county in the form of derelict mine buildings is dramatic; and the characteristic stone pumping engine house, with its tapering chimney built into one corner, is a trademark of much of the Cornish landscape. The areas where the industry was concentrated were around Wendron, west of Truro, St Ives and, of particular importance, on the Land's End peninsula around St Just-in-Penwith. Tin was also mined in association with copper around Camborne, Gwenapp, St Day and Gunnislake, and even in predominantly copper areas like Redruth and Chacewater, substantial tin deposits were actively worked.

The tin mining industry has an important place in the history of technology, for it was the problems of draining tin mines which instigated much of the work on the development of steam pumping engines, initially by Savery and Newcomen and later in the form of improvements by Watt and Trevithick. Although the Boulton & Watt beam engine was extensively used in Cornish metal mines, it was the refined version of it, the 'Cornish engine' developed by Richard Trevithick (1771-1833), which found the greatest favour and which can still be seen at a number of mine sites today. Several have been preserved as a result of the efforts of the Cornish Engines Preservation Society, set up in 1935 with the immediate objective of preserving the 24in rotative beam winding engine at Levant copper mine near Land's End (189/SW 360340), the oldest surviving engine in Cornwall. Other engines preserved are the 80in cylinder pumping engine of Robinson's Shaft (189/SW

669409) within the buildings of South Crofty Mine at Pool and built at Hayle in 1854, the 90in cylinder pumping engine at Taylor's Shaft, East Pool (189/SW 679419), built in 1892 and also at Hayle, and the 30in rotative beam-winding engine built at the Holman Foundry in Camborne in 1887 and preserved *in situ* alongside the A30 (T) at East Pool (189/SW 675416). In 1970 the Cornish Engines Preservation Society amalgamated with the Cornish Waterwheels Preservation Society to form the Trevithick Society, an active body dedicated to the preservation and recording of industrial archaeological sites in Cornwall. The engines mentioned above are now administered by the National Trust.

Once one of the most important centres of the Cornish tin and copper mining industry, Camborne still offers much for the visiting industrial archaeologist. In the centre of the town, opposite the statue of Richard Trevithick, is Holman's Museum (189/SW 647401), run by the firm that manufactures mining equipment. Here is a large collection of mining tools, a vertical steam engine of 1870, and models of Trevithick's steam engine erected at Wheal Prosper in 1811 and of his double-acting water pressure engine erected at Wheal Druid in 1800. Also preserved here is the rotative beam engine of 1850 from Rostowrack used in the china clay pits there until 1953. In Camborne, too, is the School of Mines and the Literary Institution, while  $\frac{1}{2}$  mile to the south-west at Penponds (189/SW 636389) is Richard Trevithick's cottage.

The rich tin oxide ores from the Cornish mines required crushing and concentrating before they could be smelted. Crushing was carried out under stamps consisting of vertical wooden beams shod with iron which were lifted by cams on a shaft and allowed to fall on to the ore fed into a box below. The shaft with its cams was usually powered, through gears, by a waterwheel or, less frequently, a steam engine. A working model of a set of steam-powered stamps can be seen in Holman's Museum, Camborne. Water-powered stamps or their remains can be seen at a number of sites, including Nancledra (189/SW 500355), where there are eight stamps and an 18ft diameter waterwheel which were all in use until 1948.

Perhaps the only set of operational Cornish stamps in the world can be seen at the Tolgus Tin Company's works (189/SW 690438) on the left-hand side of the B3300 road out of Redruth to Portreath. Here is a complete and working tin extraction plant which, until 1968, drew most of its raw material

from the waste coming from the deep mines of South Crofty and Geevor. Since then, mainly as the result of improved techniques of recovery from these mines, tin has been extracted from waste left at old mines, from beach sand at Gwihian and from ore received from the few surviving 'tributers', or miners working by themselves with the possible help of a son or relative. At the lower works are the stamps, at the upper works a rotary calciner, last used in 1940 to burn arsenic out of the tin ores, together with the rotating tables powered by waterwheels which separated the metalliferous material from the waste. The site, now somewhat commercialised, is run as a tourist attraction.

#### LEAD

Lead, like tin, has been mined and quarried in Britain for some 2,000 years and only in the last half century or so has it ceased to be worked. As with tin, foreign ores coming into Britain in increasing quantities in the early 1900s finally killed the remaining mines, although smelting and processing plants, relying on these overseas sources, have continued in operation. Unlike tin, which was largely concentrated in Cornwall, lead mining was much more widespread, with major working areas in Northumberland, Durham, Yorkshire, Derbyshire, North Wales, Shropshire and Somerset. The main uses for the metal during the eighteenth and nineteenth centuries were for roofing and guttering, water and gas pipes and general plumbing work, shot, and in the very purest form for the lead chambers used in the manufacture of sulphuric acid. It was also used extensively for the oxide (red lead) and the carbonate (white lead), both paint bases.

The most commonly worked lead ore was the sulphide, galena, which could be converted into metal in either specialised types of blast furnaces or in reverberatory furnaces. In some areas, notably the Mendip hills of Somerset, waste materials left behind by Roman lead smelters were reworked during the late nineteenth century, using more efficient processes.

The remains of lead mining and smelting and, to a lesser extent, the sites where lead was used commercially, provide some of the most rewarding areas of study for the industrial archaeologist. The period of working was often over many centuries and carried out within the framework of complex local laws. In Derbyshire and Somerset, for example, the lead working areas were divided into liberties within which miners could seek and mine ore

34 Snailbeach lead mines, Shropshire. Collapsed timber headgear



under specified conditions and subject to the surrendering to the landowner of dues relating to their output. Tools are abundant in museums such as Derby, Buxton and Sheffield and at the headquarters of the Peak District Mines Historical Society at Magpie Mine, Sheldon, Derbyshire (111/SK 173682), where there are also extensive surface remains. Some parts of the mining surface equipment are fairly conventional, and headstocks can be found in varying states of decay at a number of shaft mine sites, such as George's Shaft, Snailbeach (Plates 34 and 35), in Shropshire (118/SJ 375022). Elsewhere, in Derbyshire and the Dales of Yorkshire, for example, mine remains take the form of almost continuous fissures sometimes stretching over miles where the miners have followed a rake vein, as a vertical crevice



35 Snailbeach lead mines, Shropshire. Remains of ore separator with archimedean-screw feed

occupied by the ore was called. The extensiveness of lead mining, coupled with the remoteness of many of the sites and their easy accessibility, makes care and precaution in exploring them of very great importance. Often there are interesting remains underground, but the mines should not be entered without skilled and experienced guidance, which can often be found in specialist societies like the Peak District Mines Historical Society and the Shropshire Mining Club.

Once the ore was out of the ground, it still had a number of processes to undergo before it was converted into metallic lead. Remains of processing plants or, more correctly, the buildings which housed them, are prolific in many lead mining areas. They exhibit a number of regional differences in arrangement. Ore crushing was usually mechanised, with water-powered crushers. Perhaps the finest surviving lead mill site is in Weardale, County Durham (84/NY 927429), where the buildings and magnificent 33ft 8in iron waterwheel of the Killhope ore crushing plant are being preserved. Before this crushed ore could be fed into furnaces at least a proportion of the impurities had to be removed, so that the material eventually used was reasonably concentrated. This was achieved in a variety of ways, from picking over the ore by hand to various mechanised panning and washing operations. The latter techniques are used today but remains can be found

at a number of sites of the predecessors of this modern equipment. One of the most common types of concentration equipment was the buddle, in which crushed ore in the form of a slurry was fed down a wooden trough or launder into the centre of a circular stone floor. As the ore flowed down and settled on the floor, its surface was brushed by rotating arms sometimes supporting heather. The buddling process relied simply on the fact that the heavy metal-laden fraction of the ore would settle first, near the mouth of the trough in the centre of the buddle, and the concentration would diminish rapidly towards the outer edges. Thus the centre of the filled buddle could be dug out and smelted, and the material at the outer edges thrown away. Remains of buddle floors can be found on Mendip near St Cuthbert's Lead Works, Priddy (165/ST 545508). The almost completely disintegrated skeleton of a jiggging table with archimedean-screw feed, also used for ore washing and concentration, stands on the Snailbeach mining site in Shropshire (118/SJ 375022) (Plate 35).

Perhaps the most distinctive of all the site remains connected with the recovery of lead are those associated with smelting. In 1778 it was shown that lead was sublimed during the smelting of its ore, galena, and that the vapours settled in the flues and chimneys of the furnace or escaped to poison the surrounding grassland and surface water. It was also appreciated that a substantial proportion of the potentially usable lead in the ore was being lost. As the fumes were very finely divided, they settled slowly, so in order to retain them, very long flues with built-in partitions or obstructions were used to increase the time in the flue and provide sufficient surface area on which the fumes could precipitate. In some cases fine jets of water were tried in an attempt to assist settling. The most satisfactory arrangement seems to have been a long, almost horizontal flue with a vertical chimney at the end, but return flues and flues with chambers in them were also extensively used. Numerous variations on these themes can be found, defying almost any analysis of the optimum system, even if one was ever discovered. Frequently the nature of the terrain seems to have determined which type of flue was used. The flues have now often collapsed and are readily mistaken for culverts or drainage courses.

In open sites on the Pennines long single flues ran for distances of up to 2 miles from the furnace. One of very great length can be traced at Keld Heads Mill, Wensleydale (90/SE 077910). Here a Stokoe condenser was used

in the flue about 160yd from the mill, consisting of a chamber filled with brushwood which was constantly sprayed with water. Between 4 and 6 per cent of the lead recovered at the smelt mill came from condensers of this type. Beyond the Stokoe condenser the flue continues for nearly 2 miles up on the moor beside Cobscar Smelter (90/SE 060930) and both share a common chimney. At Grassington High Mill (90/SE 025663) a double arrangement of Stokoe condensers can be found, with the walls of the two compartments substantially intact. At the Surrender smelt mill, Yorkshire (90/NY 988003), is another long flue extending from the union of two smaller flues from separate ore hearths, and at Lintzgarth mill, County Durham (84/NY 925430), two flues are carried on an arched bridge across a stream and a road to enter a condensing chamber. From the far side of the chamber the remains of a single flue run for some 1½ miles across the moor.

On restricted sites flues zigzagged or were banked, grid-iron fashion, with chambers at each return. Flues of this latter type (Plate 36) can be seen at Charterhouse-on-Mendip in Somerset (165/ST 504557), and there is a zigzag arrangement at Castleside smelter in County Durham (84/NZ 078485). The Wanlockhead site in Dumfriesshire (68/NS 855144) has a curious coiled system of flues nearly 1,000yd long and the remains of a condenser which held racks of pebbles and water-soaked coke filters. Wanlockhead is also notable for the water-powered pumping engine (see p76) used to drain the workings (Plate 37).

36 Lead precipitation flues, Charterhouse-on-Mendip, Somerset





37 Water bucket beam engine at Straitsteps lead mine, Wanlockhead, Dumfriesshire

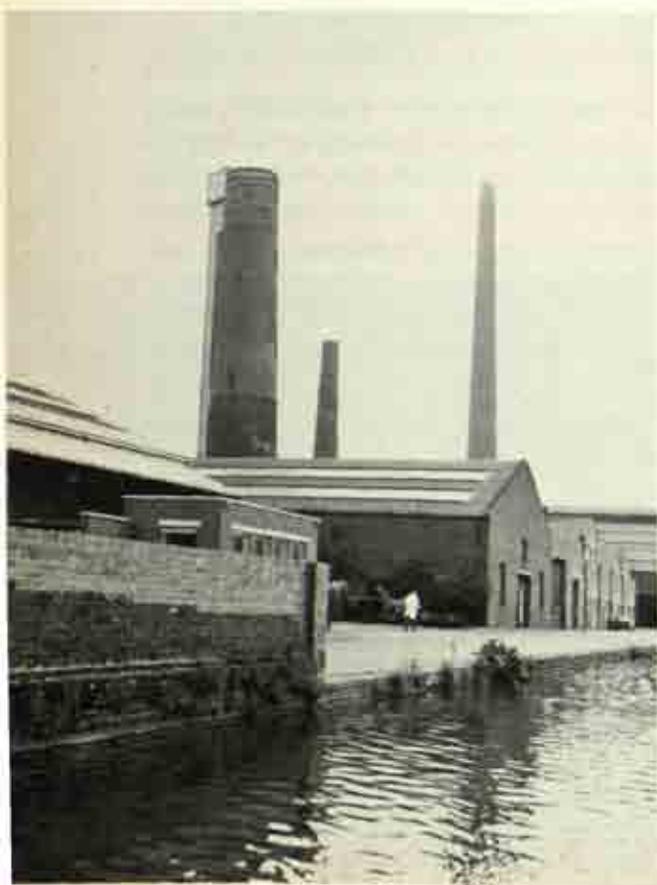
Associated with these flues were chimneys, often of considerable height, many of which still survive. Some dominate the landscape for many miles, as at Smitham Hill, Mendip (165/ST 556547), where a chimney of very Cornish appearance has been recently restored. Another 'Cornish' type of chimney of circular section tops the long flue from Langley smelt mill, Northumberland (77/NY 841611), and there is a square section stack of squat appearance at Stone Edge mill, Derbyshire (111/SK 334670). Alport, Derbyshire (111/SK 223648) has a particularly corpulent chimney designed to receive the gases from four separate furnaces. Smelt mill chimneys in the mid-Pennines area also provide the inspiration for the band of enthusiasts who form the Earby Mines Research Group. They have repaired a number of chimneys, together with buddles and dressing floors, a horse gin and various pump rod chambers.

Before leaving chimneys and flues it is worth mentioning that other metal industries also used them to a certain extent in conjunction with the refining of tin and copper, as at Crews Hole, Bristol, where a copper works chimney survives (156/ST 625733), and also in the extraction of arsenic. In the latter case the flue played a twofold role in preventing the poisonous arsenious

oxide from contaminating the countryside and by providing a means of recovery of the material for commercial use. At the Devon Great Consols mine (175/SX 425733), which was concerned initially with copper, arsenic had become the main source of income by the 1870s, as the chimney and flue system indicate. In Cornwall the Botallack tin mine (189/SW 363333) has a complete labyrinth of arsenic flues.

One product for which lead was extensively used—lead shot—required a highly specialised form of industrial building for its manufacture. By a process perfected in Bristol in the 1780s molten lead (mixed with arsenic to make it form hard and spherical globules) was poured through a perforated tray to fall up to 150ft into a vat of water. The droplets solidified as they fell and the water prevented them being damaged by impact. What was probably the first shot tower, built in Bristol in about 1787, was demolished in 1968 for the inevitable road widening, and this great loss, coupled with the

38 Shot tower in the works of Associated Lead, Chester



destruction soon after of the 174ft Elswick shot tower in Newcastle-upon-Tyne, means that there is now only one in existence in Britain (Plate 38), in the works of Associated Lead at Chester (109/SJ 415667). A shot tower that stood near Waterloo Bridge, London, was pulled down soon after the Festival of Britain in 1951.

#### OTHER NON-FERROUS METALS

Of the other non-ferrous metals which have been worked or processed in Britain, aluminium is perhaps the most important. A relatively 'modern' metal, it was considered semi-precious as recently as the 1890s and a century ago fetched £3 per ounce. The intensive demand for the metal, created particularly by the wartime aircraft industry, has made it the most important after iron/steel. The smelting industry in Britain uses imported bauxite (the ore, hydrated aluminium oxide) and because the process is electrical it is sited near sources of cheap electricity—for instance, in the Highlands of Scotland where hydroelectric generation makes smelting more economical than elsewhere. As with the smelting of copper in South Wales 150 years ago, the industry is located near its source of energy.

Although early aluminium smelters may only now be coming within the province of industrial archaeological investigation, gold mining installations in Wales provide a surprising wealth of site evidence. The gold mining industry was largely concentrated in Merionethshire north of the River Mawddach, and in Carmarthenshire. At Dolaucothi in Carmarthenshire, where the Romans had mined gold, there were revivals of activity in 1910 and the 1930s, the site (140/SN 670410) being finally abandoned in 1940. Although remains of the Roman workings, including an adit and watercourse, can still be seen, the only evidence of the recent mining is a concrete capped shaft. At Gwynfynydd (116/SH 735275) in Merioneth, however, there are substantial remains of the ore concentration plant, with steel pipes which brought water to a turbine, part of which still survives, and walls surrounding extensive working levels. The mine was worked from a number of levels, and there is a substantial headframe in one of them used for winding up and down an inclined shaft from levels lower down. Near the entrance to one of these adit levels is the strong room (116/SH 737282) where gold was stored before being transported to the mill. The site was first worked in 1864, reached its peak output in the 1901-4 period and finally closed in 1938.

## 9 Stone, Clay and Glass

THE iron industry, on which so much of Britain's industrial growth depended, relied on basic raw materials taken out of the ground—iron ore, limestone and coal for coking. So too did non-ferrous metal industries like those of tin, copper, zinc and lead. All these metal extraction industries, and their concomitant processing and refining, underwent radical changes in scale and technology during the Industrial Revolution period, which makes them a legitimate area of study for the industrial archaeologist. There were, however, other extractive industries, and manufacturing industries based on mineral or quarried raw materials, which also gained in importance during the same period. They used non-metallic raw materials, notably stone and clay. The stone industry, based largely on quarrying, was a traditional one which underwent more change as a result of increasing scale of operation than major advances in extractive technology. The products of quarrying in the form of stone for building continued to be used in the traditional manner. The main effects of industrialisation were to create enormous new demands on certain specialised sectors of the quarrying industry—for roofing slates from North Wales, for example—and it is these aspects of the industry on which this chapter will concentrate. Similarly demand for bricks, cement and later concrete was greatly stimulated by the building activity associated with industrialisation. The pottery and glass industries, also based on raw materials out of the ground, expanded enormously and developed new technologies. In the pottery industry, and largely as a result of the organisational innovations of Josiah Wedgwood (1730-95), not only were new manufacturing techniques introduced but a whole new approach to the basis of employment of workers akin to a 'production line' was devised, with specialist craftsmen each engaged on a limited area of the production process.

### STONE AND CLAY FOR BUILDING

Even before the 'transport revolution', which occurred in parallel with the development of industrialisation, stone was carried enormous distances from

the quarry to the place where it was used—Clipsham stone from Rutland to Windsor Castle, Purbeck 'marble' to Durham and many other cathedrals. With the completion of the Avon Navigation in 1727, Bath stone became even more extensively used, in London and Dublin, for example, and in the 1730s Ralph Allen built one of the first railways, to connect his Combe Down quarries overlooking Bath with the River Avon link to the outside world. The nineteenth century saw the real expansion of this long-distance transport of stone. The growth of London alone created enormous demands for stone, as it did for brick and slate also. Dartmoor granite was used for Rennie's London Bridge in the 1820s, Bazalgette's Victoria Embankment came largely from the quarries of Lundy Island, and Portland stone, already well established for the public buildings of the metropolis, became uniquely associated with the imperialist architectural *tour de force* of the Edwardian era.

Most stone is quarried, as opposed to being mined, and quarries, both working and abandoned, often yield useful information for the industrial archaeologist. Cranes, primitive railways, rock-sawing equipment, and curious little brick- or stone-built powder houses are among the site evidence to be found in disused stone quarries, which very often contain at least some other abandoned equipment too. A sandstone quarry in Bebington, Cheshire (109/SJ 315845), for example, possesses fishbelly rails on stone sleepers, thought to be part of the original track of the Liverpool & Manchester Railway and, until recently, there was also a steam-powered rock saw built in Vermont, USA.

In contrast to most building stones, Bath stone has since the 1850s usually been mined in underground galleries, many of great size. Only one, the Monks Park mine, is still in operation, but remains of others exist at Box and Corsham. The stone occurs in beds over 20ft thick, which were reached by shafts and inclines. The method of working was, in effect, the 'pillar and stall' technique in that huge stone pillars were left in the workings to support the roof as mining proceeded. The Bath stone was taken out in large blocks which were, until the 1940s, sawn by hand, but today a coal-cutting machine is used.

Of all the building materials quarried in the British Isles, Welsh slate has perhaps had the most geographically widespread use and its extraction has produced some strikingly spectacular landscapes of lunar quality. Before

about 1820 North Wales slate was mainly used locally, but with the development of the canal network in England and later of railways, the easily won and highly tractable slate became the cheapest available roofing material over most of Britain. Huge quantities left North Wales on coastal schooners and by rail to cover acres of rooftops in every industrial town and city. Only in areas such as the West Riding of Yorkshire, Collyweston in Lincolnshire and Stonesfield in Oxfordshire could locally available 'slates'—in fact they are laminar limestone—hold their own. Welsh slates, and to a lesser extent Westmorland slates, were both cheap to quarry and dress and could be provided in accurate sizes of absolutely uniform quality which, in addition to the fact that they were relatively thin, made them ideal for the hundreds of thousands of standardised workers' houses which were being built throughout the nineteenth century.

Several parts of North Wales, even today, are still totally dominated by the slate industry, which once thrived there but is now almost dead. The huge Penrhyn complex (107/SH 6265) glowers over Bethesda and the entrance to Nant Ffrancon, massive piles of waste spilling over from the working levels high above the floor of the valley, and Blaenau Ffestiniog (109/SH 7046) is almost surrounded on the north and east by old quarry workings, together with underground mines. Perhaps the most spectacular and, to the industrial archaeologist, one of the most interesting areas of slate working is to the south-east of Llyn Padarn, in the Dinorwic Quarry at Gylfach Ddu, Llanberis (107/SH 5960). Here the North Wales Quarrying Museum has been set up, under the care of the National Museum of Wales, in the quarry workshop buildings.

First worked in 1809, the Dinorwic Quarry (Plate 39), like others in Caernarvonshire, enjoyed its greatest prosperity in the latter part of the nineteenth century, peak output being reached in 1900, when some 3,000 men were employed. The workshop buildings were erected in 1870 around a quadrangle, the main entrance being through a central archway surmounted by a clock with a face of slate. Behind towers the quarry, with terrace upon terrace of workings reaching up from the shores of Llyn Padarn 1,400 ft to the top of Elidir. It closed in 1969.

The museum occupies the old workshops or, to be more accurate, the old workshops *are* the museum, for they are little changed from when they were in use, and contain much of the original equipment. A woodworking



39 Llanberis slate quarry, Caernarvon.

shop, pattern shop, foundries, smithies, fitting shops and locomotive sheds made the quarries almost completely self-sufficient, enabling the company to manufacture and maintain almost everything it required for the quarrying, dressing and transport of the slate. All the machines were driven by line-shafting from a single waterwheel of 50ft 5in diameter and 80 hp, which was the sole prime mover from 1870 to 1925, when it was replaced by a Pelton wheel that still drives some of the machinery. The foundry, dominated by a huge hand-operated wooden crane of 1872, looks as it did when working, with wooden patterns laid out for gear wheels, locomotive wheels, turntables and numerous smaller items. At the four blacksmiths' hearths all the hand tools for the quarry were made. The machine shop has lathes, a slotting machine and a drill, most dating from early this century. Slate-sawing tables can be seen and other aspects of the slate-dressing industry are to be included as the museum develops. Outside a section of narrow gauge railway along the shores of Llyn Padarn has been reinstated by a private company to carry passengers.

Although Welsh slates were almost universal roofing material for the houses and factories of nineteenth-century industrial Britain, by far the

majority of those buildings were built of brick rather than stone. Only in specific areas of Pennine Yorkshire and Lancashire did stone continue almost throughout, and even here invading terraces of red brick can often be seen. Elsewhere bricks were used for everything, the whole of the Midlands industrial area and all London but the centre being built of burnt clay from hundreds of brick-clay pits. It is in a way remarkable that something as large as a house is built of something as small as a brick but, as a manufactured building unit, the brick had and still has a lot to offer, of which convenience of handling is the most important, being related to what a bricklayer can hold comfortably in one hand. The size of bricks has thus remained remarkably consistent. A curious exception were the bricks made by Sir Joseph Wilkes at his Measham brickworks in Leicestershire during the 1790s in an attempt to beat the brick tax introduced in 1784. Known locally as Wilkes' Gobs, these bricks, almost twice the size of normal ones, can still be seen in a number of houses in Measham (120/SK 334122) and nearby villages.

Wilkes' Gobs were only successful for a short time, as in 1803 bricks larger than 10in by 3in by 5in paid double the tax. The rate of duty was substantial, starting in 1784 at 2s 6d per 1,000 and reaching 5s in 1803, when tiles were also included. In 1833 the tile tax was repealed but 2 years later the duty on common bricks was raised to 5s 10d per 1,000. All taxes on bricks were removed in 1850, a considerable sacrifice of revenue by the government, which, in the year before the duty was repealed, collected charges on 1,800 million bricks.

Throughout the nineteenth century brickmaking continued to be the highly localised industry which it had always been, located near its market as the result of heavy transport charges on articles of low unit cost. Clay suitable for brickmaking is widespread and, as these clays are very varied, even in an industrial England, where uniformity was almost applauded in ordinary buildings, brick-built houses exhibit a surprising diversity of colour and texture.

Mechanisation of the brick-making process occurred progressively throughout the nineteenth century, although some of the first improvements, such as the compacting of clay under rollers, were introduced in the middle of the eighteenth. At that date bricks were hand-moulded and often fired in clamps in which the newly dried 'green' bricks were stacked with layers



40 Conical brick kiln, Nettlebed, Oxfordshire

of slack coal under a layer of earth. Later, updraught kilns were used, the bricks being stacked in a chamber with a fire below; temperatures were much higher, greater vitrification of the clay occurred and stronger and more durable bricks resulted. As with kilns for fine china, there is great variety to be found in the types of kiln built for brick and tile firing, both intermittent and continuous. The main problem with brick firing was that it was a batch process, both expensive in fuel and time. The breakthrough came with the introduction in 1858 of a form of continuous kiln by the German engineer Friedrich Hoffman (1818-1900). The Hoffman kiln was circular, with a tall central chimney, and consisted of a series of radiating chambers which could be charged, fired and unloaded in a continuous succession. The gas flow was so arranged that the exhaust from the bank being fired dried the 'green' bricks in the next bank and air passing over fired bricks in previous chambers cooled them, while providing preheated air for the chamber being fired. Kilns of this type are now becoming rare in

Britain; remains of one can be seen at Glencaise, Perthshire (55/NO 193206), and a very large example was demolished recently at Donnington, Shropshire, although a film of its operation is held by the Ironbridge Gorge Museum. Brickmaking, together with roof tile manufacture, is one of the industries well represented in the East Shropshire coalfield and one which this museum is anxious to have represented. A small brick and tile works at the Blists Hill Open Air Museum is currently being restored, as is the adjacent clay pit winding gear. A roof tile drying floor with underfloor flues has been reconstructed and a number of tile presses, which look rather like the fly-presses seen in engineering works, have been restored to working condition. Two circular Hoffmans dating from 1866 and 1873 at William Thomas's works at Wellington, Somerset, are unlikely to survive long, but the owners have co-operated with local industrial archaeologists to ensure proper recording.

Another aspect of the tile industry which enjoyed enormous markets in the second half of the nineteenth century was the manufacture of decorative wall and floor tiles. Two of the largest makers, Maws and Craven Dunnill, had their works at Jackfield in the Ironbridge Gorge, and although the industry here is now extinct, buildings still survive and the companies' products can be seen in profusion in local buildings. Maws were in fact the largest tile manufacturers in the world at the end of the nineteenth century, producing floor and wall tiles which appear in nonconformist chapels, butchers' and game shops and stations on the London Underground. They were responsible for introducing the steam-driven tile press in 1873. Other major tile makers included Minton, Copeland and Doulton although the latter had a greater reputation for making terracotta, a material fired at a high temperature which could be moulded to intricate shapes. Unglazed terracotta and the glazed faience varieties were beloved of architects caught on the crest of the wave of Gothic revival. Without the ingenuity of the Victorian brick and tile makers, we would not have, or would have been spared, the Albert Memorial, Keble College Chapel and the Midland Hotel, Manchester.

One remaining aspect of the building materials industry demands attention—the manufacture of cement and concrete. The huge increase in building works created a need not only for cement for ordinary constructional purposes but for hydraulic cements which would set in the absence of air.

In the early nineteenth century there were numerous so-called 'Roman' cements available, makers being stimulated by the London Building Act of 1774, which encouraged stucco facings for buildings, but more by the demands of canal, harbour and railway engineers. Parker's cement was one of the better patent 'Roman' cements and was used by Thomas Telford in the construction of Chirk Aqueduct (118/SJ 287373) because of its water-resistant properties. It was also employed by Marc Isambard Brunel (1769-1849) for the Thames Tunnel (161/TQ 352800).

The first really strong cement came in 1824 when Joseph Aspdin (1779-1855) patented a mixture called Portland cement, the name deriving not from any connection with Portland but probably from a desire to take advantage of the implied quality which the name Portland gave. Portland cement was at once a success. It was made by firing a clay and lime mixture at very high temperature in a type of bottle kiln quite unlike traditional limekilns.

Limekilns are amongst the most familiar and least studied of industrial archaeological sites. The majority were simply for burning lime for agricultural purposes, but these were usually small kilns often only a few feet high. Examination of a large-scale map of an area such as the Mendips reveals a limekiln in the corner of almost every field; exploration on the ground usually produces little more than a pile of rough stones. Coastal sites were quite common, too, and the North Devon and Somerset coasts have numerous limekilns which relied on South Wales coal brought across the Bristol Channel in sailing trows. Some of the Somerset kilns were on the foreshore; the trow ran up on to the beach, stayed there over low water while its coal was unloaded into horsedrawn carts, and left on the following tide. Although many large kilns were built for burning agricultural lime, most were for making lime cement. They are frequently found built into hillsides, in much the same manner as were blast furnaces in the eighteenth century, taking advantage of the high ground at the back for charging in the raw materials and the low front for withdrawing the burnt lime. Large numbers of this type of furnace can be found associated with limestone quarried along Wenlock Edge in Shropshire. A particularly well preserved group (Plate 41) stands in the designated site of the Black Country Museum, Dudley (131/SO 949917), alongside the A4123 Birmingham to Wolverhampton road. These kilns, dramatically depicted by J. M. W. Turner 150 years



41 Limekiln built in 1842 on the site of the Black Country Open Air Museum, Dudley

ago, were served by their own branch from the nearby canal, which provided an outlet for the lime. A much more modern kiln (Plate 42) of the split-shaft type stands at Betchworth in Surrey (170/TQ 208514).

Although concrete, consisting of a cement matrix and an aggregate of stones, is often regarded as a wholly modern material, it had its origins at least 2,000 years ago when it was used in Roman bridges and other engineering works. Mass lime concrete continued to be used intermittently for foundations, and in sea walls and breakwaters, until the nineteenth century, when the first attempts were made to develop its potential further. From the 1850s Portland cement was increasingly used instead of the older lime cements and, although this created problems because setting was so much more rapid, the vastly improved strength of the newer material stimulated numerous experiments in the application of concrete for building and civil engineering. Throughout the second half of the nineteenth century attempts were made, particularly in France, to develop concrete building techniques and eventually two rival Frenchmen, Edmond Coignet (1850-1915) and François Hennebique (1842-1921), perfected concrete con-



42 Split-shaft limekiln, 70ft high, at Betchworth, Surrey

struction systems for commercial use. Coignet developed the pioneering work of his father, François (1814-88), who proposed reinforcing the concrete with iron rods and beams and from 1890 onwards patented the use of reinforced concrete for pipes, tunnels, precast beams and piles. The Hennebique system was introduced to Britain when L. G. Mouchel opened an office in London in 1897 to exploit it under licence. It embraced columns, beams, floors and walls, all in reinforced concrete, and had no rival in Britain until Coignet introduced his system in 1904.

Early reinforced concrete structures are surprisingly rare and are seldom appreciated for what they are. One of the first large concrete-framed buildings, constructed on the Coignet principle, stands near the entrance

to Bristol docks where three massive brick-clad tobacco bonds dominate the river (156/ST 567723), while a very early reinforced concrete bridge, the Free Bridge of 1908 (119/SJ 681033), crosses the Severn only  $\frac{1}{2}$  mile downstream from the pioneer iron bridge of 1779. What is perhaps the first concrete bridge in Britain, although made of mass concrete with no reinforcement, dates from the 1880s and crosses the River Axe at Seaton in Devon (177/SY 253900).

#### POTTERY

As with the manufacture of bricks and tiles, the pottery industry relies on clays which are fired in a kiln until vitrification occurs. The simplest possible classification would group pottery into earthenware, stoneware and porcelain, depending on the temperature of firing and quality of the clay and additional ingredients. Glazes are used for most pottery to make it impermeable and to produce decorative effects. Many are based on silica associated with other materials: thus lead glaze is silica and litharge, while others incorporate silica with alumina or felspar. The glaze is, in effect, a thin layer of glass fused on to the surface. Earthenware on the other hand, which is used for drain and sewer pipes among other things, was until recently glazed with common salt thrown into the kiln and allowed to vitrify on the articles being fired.

Clay suitable for pottery making is widespread in occurrence although widely variable in quality. Invariably, however, it requires pretreatment before it can be used. The first process is usually one of 'blunging', in which the clay is mixed with large quantities of water that is then sieved off from the resulting suspension. When in a stiff plastic form, it is then 'wedged', i.e. large pieces are thrown on top of each other to remove the air bubbles. Once in a suitable state for working, it may be used in three possible ways to make a pot. Firstly it can be pressed, in its plastic state, into a mould; secondly it can be thrown on a wheel; and thirdly it can be reduced to a liquid sludge and poured into a mould. The finished piece of pottery is then fired in a kiln to produce vitrification of the clay and, at high temperatures, impermeability. At lower firing temperatures glazing is essential.

Although clay for earthenware and stoneware is fairly widespread in its distribution, the raw materials of porcelain, the finest type of ceramic, occur only in limited areas. During the seventeenth century Chinese por-

celain was being imported into Europe in increasing quantities, largely as the result of trading connections forged by the Dutch East India Company after its formation in 1609. The properties of Chinese porcelain, fine quality and whiteness, were at that date unattainable in Europe, but by the mid-seventeenth century were being imitated in Delft by the use of a soft clay body covered with tin enamel. By the latter part of the century this was, in its turn, being imitated in England at Bristol, Lambeth and Liverpool. Distinct and independent lines of development are then discernible in the evolution of fine pottery, with, on the one hand the continued production of this glassy, soft paste imitation porcelain, and on the other the production of true European porcelain. A third quite specific innovation, confined to England, was the production of bone china.

The discovery in Europe of the technique of making real hard porcelain represents one of those curious but by no means unique instances of a simultaneous technological innovation occurring in more than one place as the result of similar, but unconnected, thought processes. Friedrich Bottger (1682-1719), working in Meissen, near Dresden, had pioneered the use of china clay (kaolin) fused with a calcareous flux (marble or alabaster) at temperatures up to 1,400°C and on the basis of his work Meissen porcelain became supreme, and a closely guarded secret. In France the manufacture of porcelain began at Sèvres in 1768 as the result of persistent experiments pursued by P. J. Macquer (1718-84), while in the same year the independent experiments begun in 1745 by William Cookworthy (1705-80), a Plymouth chemist, resulted in the granting of the first English patent for true porcelain. He started manufacture in Plymouth using local timber as his fuel but moved to Bristol in 1770 to take advantage of plentiful coal supplies. By the 1780s the patents, which had been taken over in Bristol by Richard Champion (1743-91), were being challenged and porcelain manufacture began in Staffordshire. One of these Staffordshire potters was Josiah Wedgwood.

The mineral which provided the key to the porcelain secret was kaolin, the product of decomposition of granite. The components of granite are quartz, mica and felspar and it is a decomposition of the felspar (aluminium silicate) by a process known as kaolinisation which produces china clay. Most of the china clay found in Britain has come from the granite massif of Hensbarrow, north of St Austell in Cornwall, but the Lee Moor area on the

slopes of Dartmoor above Plymouth has also been important. At first sufficient supplies could be found in small pits close to the surface, but as these became worked out and as demand grew, much larger and deeper clay excavations were carried out, reaching in recent years depths in excess of 400ft. By the mid-nineteenth century huge quantities were being sent to continental Europe, notably Hamburg and Antwerp, but the largest single market was Staffordshire, which by then had become firmly established as the pottery centre of Britain. The siting of the industry here, at such a long distance from the source of clay, is explained largely by supplies of fuel. The pottery industry is to a great extent located near its fuel supplies, which in this case was Staffordshire coal; the additional pull of this area was the already established tradition of pottery manufacture based on locally available clays.

To the industrial archaeologist the china clay area of Cornwall provides perhaps the most extreme example of a landscape of earlier exploitation, with huge pits separated by vast glistening white tips of the mica waste washed from the kaolin. Despite this, it is a man-made landscape which, perhaps more than any other, has a stark almost ghostly drama and magnificence about it. Like the tin mine engine-houses elsewhere in the county, the clay waste tips of St Austell are now a hallmark of the Cornish landscape.

Evidence of the clay processing can be seen in a number of places but nowhere is the range of equipment as complete as at Wheal Martyn (185/SX 004555), west of the A391 St Austell to Bodmin road. Closed in 1966, this is perhaps the last small family clayworking in Cornwall where all the intricate hydraulic processes connected with the separation and settling can still be seen complete. On the site is a 25ft diameter overshot waterwheel which by means of a crank drove a flat connecting rod that operated a pump through a bellcrank. This pump lifted the clay slurry and allowed it to flow through mica drags, from which the refined liquid gravitated to settling tanks and finally kiln tanks. As the water evaporated, the clay thickened and was finally spread on a floor, below which were flues from a coal fire. After drying for some 12hr the clay was cut from the pan and thrown into a storage shed alongside known as the lincay. The Wheal Martyn site is surprisingly complete, and, in addition to the equipment listed above, a large 35ft diameter waterwheel used to operate, by means of flat rods, another pump 2,000ft away. Shortly before it closed, Wheal

Martyn passed from the ownership of the Martyn family, who bought the site in 1790, to English China Clays, which intends to develop there an open air museum based on the conservation *in situ* of the surviving remains. In addition a number of other sites are being preserved, including, at Park-andillack clayworks near St Dennis (185/SW 945568), a 50in beam pumping engine of 1852 complete with Cornish boilers and dog's pawmarks cast into the iron beam! West of the engine is a 'button-hole launder', or wooden box containing a number of plugs for draining the pit, and an extensive series of micas.

Two other clayworks' pumping engines survive in Cornwall in addition to the Rostowrack 22in engine preserved in Holman's Museum in Camborne. One, still in its original engine-house at Goonvean (185/SW 947552), is a 50in Cornish beam pumping engine of 1863, and the other has been removed from its original site at Greensplatt Clayworks, Garthew (185/SW 997554), and re-erected in a park-cum-museum open air site at Wendron Forge (189/SW 680315). Another rare survival at Slip Chinastone Quarry, also at Goonvean, is an overhead aerial ropeway still used for raising clay out of a 250ft deep pit.

Having examined the origins of kaolin, the raw material of the porcelain industry, let us consider the production end of the process and in particular the main centre of pottery making in Britain—the 'five towns' of North Staffordshire centred on Stoke-on-Trent. When in 1782 hard paste porcelain was first made at New Hall near Shelton, Staffordshire was already well established as a pottery-making centre. There was coal, a wide variety of clays and a firm tradition of potting. Even in the late sixteenth century Burslem and Hanley were producing jars, bottles and butter-pots, lead-glazed and fired with coal dug by the potters themselves. By the 1680s a second method of glazing became available with the introduction of salt glaze from the Low Countries, but neither of these processes, when applied over the common brown clay of the area, resulted in a product with the appeal of Delft. Pale Shelton clays were used in the first steps towards a finer white-bodied ware, and eventually a fine white salt-glazed stoneware evolved from a white-burning clay mixed with fine grit and sand. It enjoyed great popularity during the eighteenth century, being hard, translucent and as near to porcelain as could be reached short of the real thing. John Astbury (1688-1743) was instrumental in developing this ware and also

in utilising ground flint (silica) in the body material as a whitener. Initially the flint was ground dry under stamps rather like those used in Cornwall for crushing tin ore, but the problems of silica getting into the lungs of men working the crushers soon resulted in the development of a process for grinding underwater.

One of these flint mills is preserved in operational condition at Cheddleton in Staffordshire (110/SJ 974525). The original mill on this site was built as a corn mill, certainly before 1694 and probably much earlier. The present North Mill building dates from the 1750s or 1760s, and was probably built by the famous millwright and canal engineer James Brindley (1716-72). In the 1770s the original mill, by now known as South Mill, was converted for flint grinding also. Two undershot waterwheels driven by the River Churnet provide power for the grinding machinery, while set into the bank of the nearby Caldon Canal are kilns for calcining the flint. The Flint Mill Preservation Trust was formed in May 1967 and the mill opened to the public in April 1969.

Despite all these attempts during the eighteenth century to produce a superior form of stoneware, it was not until the introduction of real hard-paste porcelain, based on china clay, in the 1780s that Staffordshire began to produce wares of the highest quality. Even the introduction of this new technique might not have brought Staffordshire real fame and fortune had it not been for the entrepreneurial skill and organisational ability of Josiah Wedgwood (1730-95).

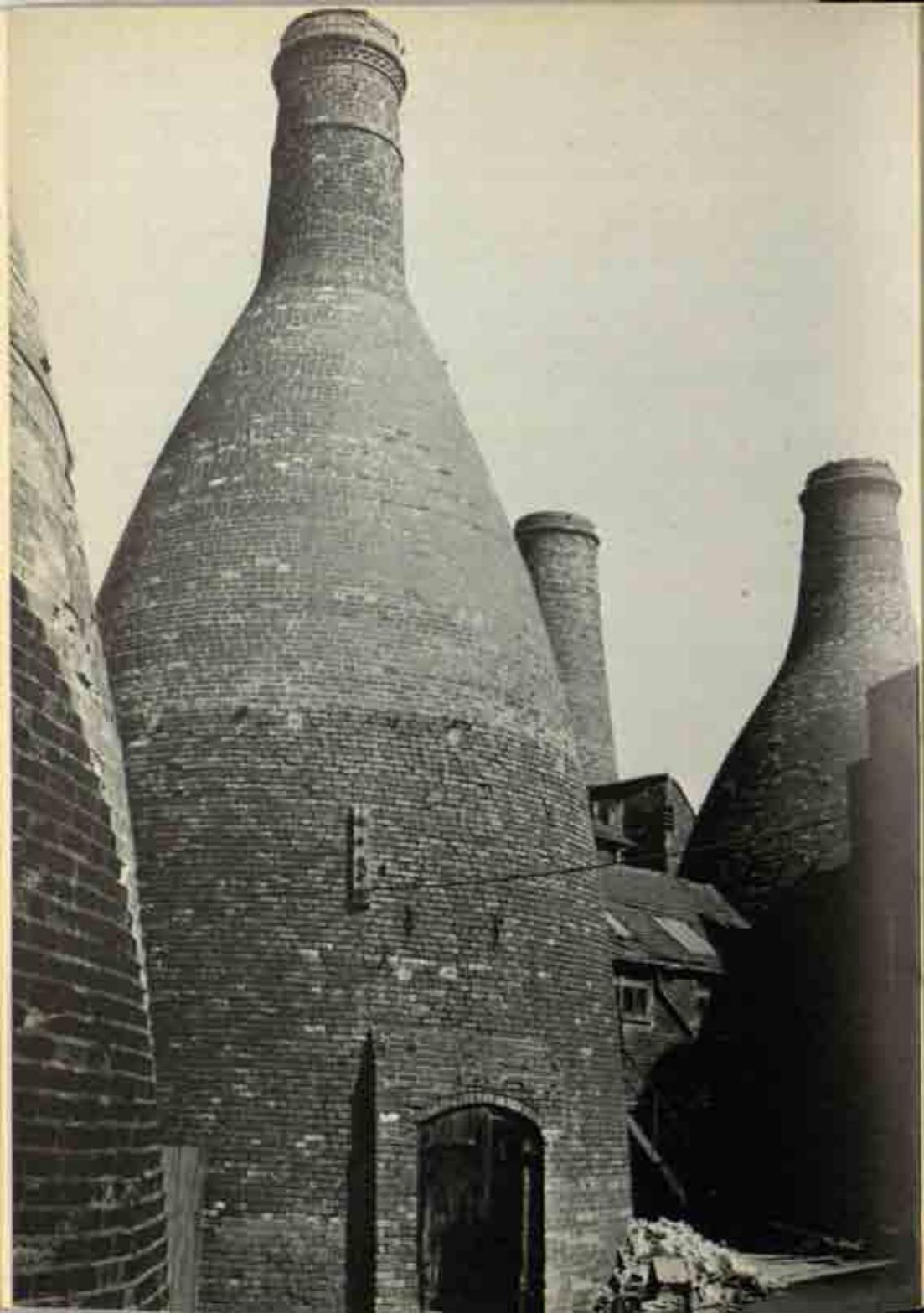
Brought up as a potter, Wedgwood set up on his own account at Burslem in 1759. One of his initial successes was a fine green-glazed ware, which he followed up by an improved stoneware evolved from earlier creamwares. Having obtained royal patronage, he called it Queen's ware and it was soon being made in dozens of potteries and used all over the country. Wedgwood never looked back. With newly introduced steam power to drive flint mills and lathes for producing refined shapes, the Staffordshire pottery industry was on the way towards rapid and large-scale expansion. But the expansion was not based solely on mechanisation and increased demand. Wedgwood developed a new works at Etruria in which to develop mechanised pottery manufacture, but he realized that to optimise the benefits which powered machinery afforded he had to press the division of labour to the maximum, with each distinct process identified and separated. He aimed at a production

line process in which individual craftsmen expressed their skill in a limited field, arguing that this afforded them greater opportunities for developing their latent abilities. The specialisation within the labour force was geared to a graded pay structure ranging from 42s per week for an experienced modeller to 1s a week for the least skilled. There can be little doubt that Wedgwood's friendship with Matthew Boulton (1728-1809), the entrepreneurial half of the partnership with James Watt, stimulated many of the ideas he introduced. By the time of Wedgwood's death in 1795 the industrial revolution in the pottery industry was in full flood.

To travel through 'The Potteries' only 25 years ago was an experience shattering to the eye and the nose. Hundred upon hundred of bottle-shaped kilns stuck up through the skyline of smoke-blackened terrace houses. Today almost all those bottle kilns have disappeared as the industry has rationalised and adopted new techniques. Tunnel kilns, completely automated in their operation, have replaced the long established 'potbanks' with their bottle ovens and uncomplicated processes. As a result of this change, and in order to try and preserve something of the old methods, the Stafford-

43 Gladstone Pottery, Longton, now being preserved by the Staffordshire Pottery Industry Preservation Trust





shire Pottery Industry Preservation Trust was set up with the specific objective of saving from demolition Gladstone Pottery (Plates 43-4) in Longton (110/SJ 912434). The aim here is to create a museum in the existing buildings, the best surviving example of a potbank, scarcely touched by twentieth-century technology, where the old processes are being carried out. Displays include not only the products but also contemporary information on the supply of materials and distribution of finished wares. A project somewhat similar in concept is scheduled for another early group of pottery buildings at Coalport on the banks of the River Severn in Shropshire (119/SJ 695024). Here the Ironbridge Gorge Museum Trust intends to restore the works, together with their bottle kilns, where Coalport china was made from the mid-eighteenth century down to the 1920s. The Coalport company moved to Stoke and is now part of the Wedgwood Group but the original pottery survives substantially intact and will be used as a museum illustrating all aspects of the clay industries of the Ironbridge Gorge, ranging from Coalport china to decorative floor and wall tiles. The craftsman potter already established at the Blists Hill Open Air Museum will move to Coalport, where the processes of manufacture of porcelain will also be demonstrated.

#### GLASS

The earliest man-made glass dates from about 4000 BC, when it was used in Egypt and Mesopotamia as a glaze for beads. By 1500 BC hollow glass vessels were in use; they were probably made around a clay core which was chipped away when the molten glass had solidified. At about the same date small objects, such as pieces of jewellery, were being made in glass by pressing between clay moulds, and finishing by grinding and polishing was also becoming common. The high temperatures necessary to smelt the raw materials for glass were achieved in simple furnaces, the glass being contained in a crucible made of a refractory substance such as clay that had a higher melting point than the glass itself. Possibly in the first century BC mouth blowing of glass, using a blowing iron, was introduced, and this remained the main method of glass forming for nearly 2,000 years. Blown glass vessels

44 Bottle ovens at Gladstone Pottery, one of the few remaining potbanks where these once common features of the Potteries still survive

of Roman origin are quite common, and it was probably during the Roman occupation that glass was first made in Britain. Traces of Roman glass furnaces have been found at Wilderspool near Warrington and Caistor-by-Norwich. In the first century AD glassmakers had mastered the art of making clear transparent glass, a great improvement over the earlier opaque types, and delicate colours could be consistently achieved by adding a variety of chemical ingredients. Glazed windows were in use by the first century AD also, particularly in the north European areas of the Roman Empire.

Glass is a crypto-crystalline substance solidified from a variety of inorganic materials melted at high temperature, that is its molecular structure does not exhibit a crystalline pattern. Many different glasses, with properties varying according to the raw materials used, are made today. The main ingredients of almost all commercially important glass is silicon dioxide ( $\text{SiO}_2$ ), often found in the form of sand. In its pure state very high temperatures (over  $1,500^\circ\text{C}$ ) are necessary to fuse silica, but glass which melts at much lower temperatures can be made by adding fluxing agents such as soda ash ( $\text{Na}_2\text{CO}_3$ ) to the silica sand. The melting temperature can be reduced to about  $800^\circ\text{C}$  by adding 25 per cent of soda ash but the resulting substance, waterglass ( $\text{Na}_2\text{SiO}_3$ ), as its name implies, is soluble in water. Addition of a stabiliser such as limestone ( $\text{CaCO}_3$ ) results in a non-soluble glass. An ordinary glass bottle or jar contains approximately 55 per cent sand, 25 per cent soda ash and 20 per cent limestone. To assist melting, 15-30 per cent of scrap glass or 'cullet' of the correct composition is usually added to the ingredients, which are known as the 'batch'.

Silica-soda-lime glasses are by far the most important group in terms of tonnages produced and variety of uses. The ingredients are cheap and easily obtained, the glass is well suited to shaping and it has good chemical-resistant properties. The colour of these glasses tends to be greenish, a result of the natural iron content of most sand, and in the case of old bottles where colour was immaterial the iron imparted an almost opaque blackish-green appearance. The cheapest bottle glass of the eighteenth or nineteenth centuries was of this crude and unrefined type. In evidence presented to the commissioners at an excise enquiry in 1831 it was stated that the materials used in common bottle glass were sand, soap-makers' waste, lime, common clay and ground bricks. Flint glass, from which tableware was produced, contained pearl-ash, litharge or red lead, Lynn or Alum Bay sand (particularly low in iron) or

'Yorkshire stones burnt and pulverised'.

Lead glasses have a high refractive index and electrical resistivity, and consist primarily of silica sand with as little iron as possible, potash and lead oxide. High quality table glass is made of lead glass, which, because its viscosity does not increase at a rapid rate during cooling, is particularly suitable for hand-made production; and also for engraving and cutting, an art that became highly developed in the late eighteenth century. Since the late seventeenth century lead glass has been used and known as 'English crystal'. Its constituents are more expensive than those of common glass, the amount of lead varying considerably—up to 92 per cent of lead oxide in some cases. A modern high-performance glass composed of high-purity silica sand and boric oxide is borosilicate glass. The boric oxide acts as a flux, permitting a reduction in alkali content that results in improved chemical stability and electrical properties. Developed early this century to cope with the problem of rain on hot railway signal-lamp lenses, borosilicate glasses are now widely used where extreme thermal conditions occur, and their low coefficient of expansion and durability makes them ideal for industrial use and for ordinary heat-resistant domestic ovenware. Coloured glass is as old as glass itself but methods of production and knowledge of the chemical additives needed were at first crude and unscientific. Empirical methods, however subject to variation in the quality of the final product, produced some spectacular results, of which the rich glowing blues and reds of medieval church windows are the most notable examples surviving today.

There is little evidence available of the furnaces used by early glassmakers, but Theophilus in his *Diversum Artium Schedula* of the twelfth century AD describes a rectangular furnace divided into two unequal parts; in the smaller section the raw materials were heated to form a vitreous mass known as 'frit', which was broken up and melted in pots sunk in the hearth of the larger part of the furnace. Agricola in the mid-sixteenth century also describes furnaces in two parts: the oven-shaped fritting furnace, with pots for the molten glass arranged round a central hearth, and the annealing furnace, oblong in shape with a small hearth below the floor. Annealing is an essential stage in the manufacture of most glass. Because of its low thermal conductivity, the surface of glass cools and therefore shrinks more quickly and to a greater extent than the interior. If unchecked, enormous stresses would

be set up within the object, leading to breakage, but this can be avoided by slow cooling at a controlled rate. This is annealing, which takes place in an oven or lehr. In a modern glassworks, for example, bottles pass slowly through the lehr on a conveyor belt and over a period of some 2hr the temperature is gradually reduced from about 540°C.

All early furnaces were fired by wood, the wood ash providing the necessary alkaline flux. One example of a type of wood-fired furnace introduced in the sixteenth century into Britain by French and Flemish glassworkers survives almost *in toto*. It was discovered in 1968 at Rosedale in the North Yorkshire Moors and later moved to the Rydedale Folk Museum, Hutton-le-Hole, near Helmsley, Yorkshire, where it was partially reconstructed and is on view to the public (86/SE 705900). The Rosedale glassworkers were perhaps the most isolated group among the numerous glassmaking families who came to England in large numbers in the 1560s and 1570s and set up furnaces in the heavily wooded areas of the Weald, and in Hampshire and Staffordshire. Fig 26 illustrates the probable original layout of the Rosedale furnace, which corresponds almost exactly with furnaces in use in Northern France in the late sixteenth century. Ingredients for the glass were heated in clay crucibles made on the site from locally available clay and baked in the side arches (F) of the furnace. The wood fuel was burnt in the central hearth (A), and burning gases circulated inside the chamber and through linnet holes or lunettes (E) into the side or wing arches. Glass was melted in crucibles (C) and the glassworkers standing at the side of the furnace inserted their pipes into the molten glass through holes (D). With the exception of a small access hole, these apertures would be stopped up with a clay filling during operation, the clay being broken away to allow removal of the crucibles for recharging. After fashioning, the glass, which in the case of the Rosedale furnace consisted largely of drinking vessels, bowls and similar utensils, was annealed in the side arches, and these were also used for fritting and heating the crucibles. The temperature of the wing arches could be controlled to some extent by partially or wholly closing the linnet holes from the hearth area.

Probably many other furnaces of this pattern were set up, mainly in southern England, where timber supplies were reasonably plentiful. Competition from the shipbuilding and iron industries was growing, however, and in 1615 there was a Royal Proclamation forbidding glassmakers to use wood for fuel. Availability of coal now became the chief locational factor,

## THE ROSEDALE GLASS FURNACE

### Presumed plan at working level

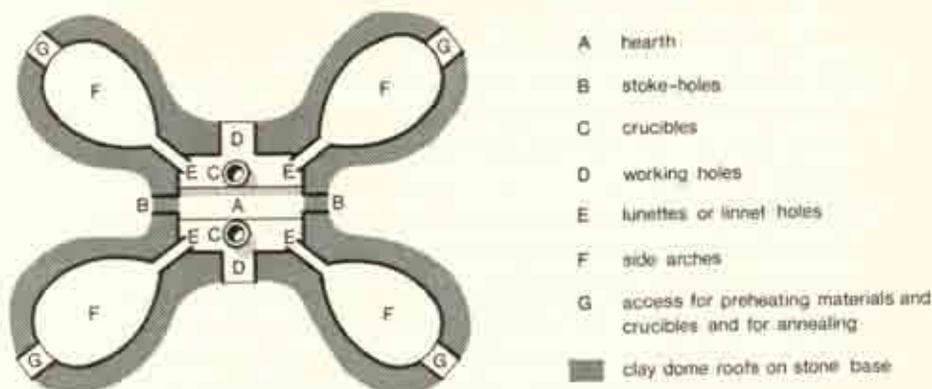


Fig 26

together with suitable sources of clay and the convenience of transport systems. The first coal-fired furnaces were probably modifications of the Rosedale pattern. During the seventeenth century a distinctive and completely new type of coal-fired furnace was developed in England, using the reverberatory process, in which the burning gases came into direct contact with glass in open crucibles. The English glassworks, consisting of a truncated cone up to 80ft high and with a base diameter of some 40–50ft provided the foundation for the industry on a large scale and was copied in Europe also. So significant was this furnace that it was included in Diderot's *Encyclopedie* in the late eighteenth century, one of the few pieces of British manufacturing technology specifically mentioned. The tall cone fulfilled a dual function, by providing cover for the glassworkers and a high level outlet for the furnace situated centrally on its floor. The grate was at approximately ground level, with a combined flue and ash tunnel running beneath it and extending across the building. The furnace would have between four and ten glass pots, with a flue between each. Immediately abreast of each pot and between two flues was an aperture called the working hole, used for introducing the raw materials and getting out the molten glass.

The furnace was fired by coal shovelled through a square fire hole on to a grate in the centre. The flames or smoke were directed towards the sides, around the glass pots, and discharged up the flues to escape into the central chimney of the cone itself. A ten-pot cone consumed 18–24 tons of coal per week. In addition to the principal furnace around which the glass blowers worked, there was also a small subsidiary furnace or 'glory hole' for softening vessels during fabrication when they were too large to be heated in one of the working holes. A long gallery, the *lehr* or annealing arch, opened at one end into the cone and the completed glassware was placed in this to cool gradually.

The crucibles in which the glass was melted had to be carefully made to prevent cracking in the intense heat of the furnace and to resist the solvent action of molten glass. They were commonly made of five parts Stourbridge clay, a very pure refractory clay notably free from lime and iron oxides, together with one part burnt clay or 'grog' obtained from old crucibles ground down to a powder.

Some five glass cones still survive in Britain, the most prominent monuments of the eighteenth- and nineteenth-century glass industry. The oldest of these, older indeed than any other cone in Europe, is at Catcliffe near Sheffield (103/SE 425887). It is the last survivor of at least six glasshouses known to have been built in the area in the eighteenth century at the height of the prosperity of the South Yorkshire glass industry. The industry became established in the Bolsterstone area in the mid-seventeenth century and by 1696 three glasshouses were in operation—one near Ferrybridge, probably at Glass Houghton, and two near Silkstone. William Fenney, works manager at Bolsterstone, left there in 1740 with a workman named Chatterton to start production in his own works at Catcliffe, 10½ miles to the south-east. Two cones were erected and one of these survives today, substantially complete, 60ft high and with a base diameter of some 40ft. It has recently been restored. Excavation of the flue beneath the cone, which contains no remains of the furnace or ancillary buildings, has revealed that glass bottles were being made there down to the early 1900s when C. Wilcocks & Co owned the works, but flint glass and jugs, vases and flasks, often decorated with opaque white stripes, were known to have been made at least as late as the 1870s.

Of the numerous other glass manufacturers established in South Yorkshire

during the nineteenth century little else remains, although a firm originally established at Worsborough Dale in 1828 is still active in Barnsley as Wood Bros Glass Co Ltd. The oldest surviving glass firm in the area, dating from 1751 and now known as Beatson Clark & Co Ltd of Masborough, Rotherham, has preserved many examples of the glassware produced in the nineteenth century, including very good examples of glass engraving.

In the North East, at Lemington, near Newcastle-upon-Tyne, is another glass cone (78/NZ 184646) which, although somewhat later in date than Catcliffe, provides a visual reminder of the industry that became important in the region from the early years of the seventeenth century, attracted primarily by cheap coal. In 1615 Sir Robert Mansel obtained a patent for making glass with coal, and, after trying to start a works in London and elsewhere, 'was enforced for his last refuge contrary to all men's opinion to make triall at Newcastle upon Tyne where after the expense of many thousand pounds that worke for window-glasse was effected with Newcastle Cole'. Glassmakers from Lorraine came to Tyneside about this time also and by the end of the seventeenth century were working at South Shields, where plate glass became important. By the mid-nineteenth century glassmaking had become an important manufacturing industry in the North East, and flint glass, crown glass for glazing, and bottles were produced. The Wear glassworks, established at Sunderland in 1842, to produce a new kind of sheet glass called rolled-plate that was rather like unpolished plate glass, achieved a worldwide reputation after supplying the glazing for the Crystal Palace in 1851.

The Lemington Glassworks, famous in the nineteenth century for flint and crown glass, was founded in 1787 by 'a company of enterprising gentlemen (who) entered into the glass trade in Newcastle under the firm of the Northumberland Glass Company'. They were granted a lease of the site at Lemington and quickly erected their first glasshouse, which was called 'the Northumberland Glasshouse'. Within a short time there were three more, including one which was very lofty and built of brick. This is the cone which still stands at Lemington. The site is now occupied by Glass Tubes & Components Ltd, but the cone is no longer used.

Other glass cones may be seen at Stourbridge, Worcestershire (130/SO 894864), and Alloa, Clackmannan (55/NS 881924), while in Bristol the truncated base of a glass cone of about 1780 has been converted into a

restaurant for a new hotel (156/ST 592723). The incomplete remains of a cone also survive within the works of Pilkington Brothers, St Helens.

Comprehensive physical remains of the glass industry in the nineteenth century, when processes were changing rapidly, are hard to find today, but there are two excellent museum displays which, although they contain little actual manufacturing equipment, go a long way towards explaining the various techniques. The Pilkington Glass Museum at St Helens, Lancashire (100/SJ 498946), illustrates all the major stages in the development of the industry, concentrating particularly on the production of flat glass. The method of making plate glass of high quality by casting was introduced into Britain from France in 1773, when the British Cast Plate Glass Company, as it became called after 1798, was established at Ravenhead, St Helens. Part of the Ravenhead casting hall and works still stands within the Pilkington complex, and there are hopes of turning them into a museum to house some of the heavy equipment of flat glass making.

The second museum display of note is in the Science Museum, South Kensington, and was opened in 1968 as a gallery of glass technology. Two booklets prepared by the Glass Manufacturers' Federation, *Glass History* and *Making Glass*, are available at the museum. There is also a descriptive catalogue listing all the exhibits and illustrating many. Unlike the St Helens museum which contains fine representative collections of art glass, the Science Museum gallery concentrates almost entirely on the manufacturing techniques, with examples of various products to illustrate advancing glass technology. Although little glassmaking equipment survives, the everyday products of the industry over the last century and a half, particularly in the form of glass containers and window glass, are commonplace.

Glass wine bottles began to replace leather and earthenware ones in the second half of the seventeenth century. At first wine, like beer, was stored in barrels, and bottles were used mainly for carrying drink from the wine merchants to the tavern, for limited storage and for serving at table. The earliest glass bottles for this purpose were pale green and globular, and of light weight. Having no flat base they were usually 'wanded', that is encased in basketwork, or placed in metal stands on the table. In 1731 wanded bottles were advertised at 42s a gross and common black bottles at 20s a gross. The practice of having bottles embossed with a seal, often dated, grew up in the 1660s, and is a useful aid to tracing the evolution in the shape of wine

bottles. Towards the end of the eighteenth century bottles became less globular, acquiring an angular shoulder between body and neck. At the same time the 'kick up', a concavity in the base of the bottle which aided stability and assisted annealing in the days before the development of the tunnel lehr, was increased in size. A fine collection of wine bottles, together with some bottle-making moulds, is exhibited in Harveys Wine Museum, Denmark Street, Bristol (156/ST 584729).

In the early seventeenth century it was discovered that beer could be kept almost indefinitely in bottles, and that, with a small amount of secondary fermentation occurring after bottling, it could actually improve in quality. The heavy taxation on glass was an initial restraint to the widespread adoption of bottles, but with the repeal in 1845 of the Excise Acts, which had imposed a tax of 8s 9d per cwt on glass bottles, the industry expanded rapidly.

A major problem with beer and the new carbonated soft drinks was to devise a satisfactory bottle closure. In 1872 the internal-screw stopper was patented by an Englishman, Henry Barrett, and in 1892 the familiar crown cork by an American, William Painter. Louis Pasteur's theories of food preservation were meanwhile put into practice in a Copenhagen brewery, which produced the first pasteurised beer. Earthenware bottles had been used by the early pioneers of soft drinks such as Jacob Schwegge, a Swiss who set up business in Bristol in 1794, but the wired-on cork closures were never satisfactory because they dried out and leaked. The egg-shaped glass bottle was introduced in 1814 to overcome this problem. It had to be stored on its side, thus keeping the cork moist. The egg bottle survived even after the introduction of the crown cork had made the shape and the need for flat storage unnecessary, and was in fact in use until the 1920s.

The best known and most successful internally stoppered bottle, patented by Hiram Codd of Camberwell in 1875, had a glass marble pressed against a rubber ring in the bottle neck by the gas pressure in the drink. Codd bottles were used in Britain from the late 1870s until the 1930s, and between 1890 and 1914 were the most widely used containers for carbonated soft drinks. An exceptional collection of soft drink bottles, together with bottle equipment and gas making plant, was found recently in the works of J. B. Bowler of Corn Street, Bath, and is now being preserved by a newly formed trust.

Widespread preservation of food in glass containers began in the United States in the 1860s after the invention in 1858 of the screw-topped jar by

John Landis Mason. American domestic food-preserving jars are still known as Mason jars. In Britain the similar Kilner jar did not come into general use until the 1920s. Automatic jar manufacturing and filling machinery developed in the 1900s; it was followed in 1923 by the invention of the roll-on closure and in 1926 by the pry-off cap still used today. Bottling of milk began in the 1880s on a small scale, but it was not until the 1920s that pasteurised milk deliveries in bottles replaced milk sold 'loose' from churns in the streets. In 1934 bottled milk with a card disc closure was introduced in schools at a cost of  $\frac{1}{4}$ d for one-third of a pint. Today the milk bottle has the more hygienic foil cap and the wide-mouthed card-stoppered bottle has completely disappeared. Even the foil topped bottles of 5 years ago have now given way to lightweight versions, with carefully contoured shoulders to eliminate internal stresses.

The crown window-glass process was the earlier of the two chief methods of making sheet glass by hand and was in common use until the early years of the nineteenth century. Molten glass on a blowing iron was formed into a large hollow sphere. Then a 'pontil' or solid iron rod was attached to it by a nodule of the molten metal—glass is referred to as metal in a glassworks—and the blowing iron then removed. Reheating the glass on the rotating pontil reduced it to a soft and semi-molten state in which centrifugal force caused it to flash into a disc. The thin fire-polished disc of glass was removed from the pontil for annealing and then cut up into sheets. Every sheet made by this method had a bull's-eye or 'crown' from which it took its name, this being the point where the pontil had been attached. The sizes of pieces of glass made by this method were severely restricted, and after about 1830 the process gave way to hand cylinder-glass making. Crown glass is easy to recognise in window panes by the fine ripples and flow lines which form arcs in its surface. The larger the radius of the arc the nearer the edge of the glass disc was the sheet cut.

The hand-cylinder process of sheet glassmaking was brought to England from Lorraine in 1832 by Lucas Chance. It was essentially a development of the crown glass method, but instead of a sphere and then a disc of glass, an elongated bulb was made 12–20in in diameter and 30–70in long. The ends of the cylinder were removed, it was cut down its long side and, after reheating, the glass was flattened in a flattening kiln. The sheets were much larger than those of crown glass, were free from the central boss and were much

cheaper to make. In 1839 Sir James Chance (1814-1902) invented a method of grinding and polishing sheet glass, giving it the brilliancy and transparency of plate glass that had been similarly treated.

The third method of making sheet glass was to cast it in plates, a process developed in France in the 1680s and introduced to England in 1773. The great casting hall at the Ravenhead works, St Helens, where the technique became established, still partially survives as one of the largest industrial buildings of its day, 113yd long by 50yd wide. The method of making plate was to pour molten glass on to a flat table, first made of copper and later of cast iron, and when it had cooled and been annealed, over a period of about 10 days, the two faces of the glass were then ground and polished. A number of other firms were set up to cope with the enormous demand for flat glass as a result of the building explosion in early nineteenth-century Britain. The St Helens Crown Glass Company was formed in 1825, the Smethwick firm of Chance & Hartley brought continental glassmakers to blow cylinder glass in 1832 and in 1836 the great Union Plate Glass Works was set up at Pocket Nook, St Helens.

All these processes are well illustrated in the Pilkington Glass Museum, St Helens, and the glass technology gallery in the Science Museum, but little, if anything, survives of actual equipment. Modern manufacture of float glass and rolled sheet glass can be seen at the Pilkington works; visits for parties can be arranged through the curator of the museum. The float process, developed at St Helens in 1959, is one of the major advances in glassworking of recent years and consists of flowing glass on to a bath of molten tin to ensure a perfect under surface, the heat applied above producing a similar effect on the upper face. Ordinary sheet glass is also now made by a continuous process in which the molten 'metal' is drawn vertically from the melting pot between powered rollers.

## 10 Textiles

ONE of Man's earliest manufacturing techniques was the making of cloth by the spinning and weaving of animal and plant fibres. Before large-scale mechanised industrialisation began in Britain, the making of textiles was widely dispersed throughout the country and was of very great importance in the national economy. Wool, and later various woollen cloths, formed the largest export commodities from the medieval period through to the middle of the eighteenth century. International specialisations grew up between different production areas in Europe, and the fact that English wool was considered to be of the highest quality led merchants, particularly Flemish and Italian, to come in search of it. English taxation on wool exports led to a change in the trade as dyers and finishers abroad realised they could circumvent the tax by buying white undyed broadcloth instead of the wool itself. Broadcloth exports from the West of England rose dramatically, as did the lighter fabrics produced in East Anglia, though to a lesser extent, as they were not quite so popular. A large, rurally based cloth industry began to develop in the West of England—in Somerset, Gloucestershire and Wiltshire particularly—based on capitalist clothiers who bought wool, gave it out to hand-spinners and hand-weavers to convert into cloth, then carried out the fulling themselves and finally sent the cloth, undyed and unfinished, to Europe. In Yorkshire, which did not engage in the export market to such a great extent, the structure of the industry was somewhat different, as the clothiers, particularly in the Halifax area, were independent masters in their own right, owning their spinning wheels and weaving looms, buying wool and yarn and taking their pieces of cloth to the Cloth Hall every week for sale to merchants whom they faced as owners of the cloth they sold. The Cloth or Piece Halls of the West Riding became the symbols of an industry where the structure of production was based on a large number of masters, some of whom would be working in family units and others as employers of labour on a very small scale.

Before the coming of factories, therefore, a proletariat was already developing in many textile regions. Only in the West Riding of Yorkshire did the actual manufacturers have any degree of independence, though

theirs was the independence of capital only. Elsewhere—in the West of England, around Norwich, in the worsted area around Bradford, Yorkshire, and in the Nottinghamshire stocking and lace manufacturing districts—the man who organised production and who owned the capital in production was the clothier or 'putter-out' of work, the cloth merchant or the hosier. As most of the capital in the industry was in the raw material and goods in various stages of processing, the merchant was able to control production throughout its course. He owned the materials right through the sequence of processes, paying spinners and weavers for their labour and often renting out the equipment, sometimes to many hundreds of dependent families. The structure of ownership which was later to characterise the factory system, therefore, already existed in several regions of the country in the days of the cottage-based industry, long before the development of modern machine processes.

In order to appreciate the significance of later innovations it is important to look at the processes through which textile fibres went during their conversion from raw material to finished cloth. The stages were substantially the same for all textiles, although here reference will be made mostly to wool, which was dominant before industrialisation. As will be seen later, a development in one branch of the textile industry often had very direct relevance to another, so that from the middle of the eighteenth century onwards the progress of the wool, cotton and to a certain extent flax (for linen) industry went hand in hand.

Wool textiles may be divided into woollens and worsteds. Woollens use short fibre or short staple wool, and worsteds longer staple. In both cases the wool is first washed and cleaned to remove natural grease and dirt, after which there are different techniques for the two fabrics. For woollen textiles the raw wool is 'carded' to lay the tangled fibres into roughly parallel strands so that they can be more easily drawn for spinning. Before the eighteenth century carding was done by hand using two oblong boards, each of which had on one of its sides projecting wires or nails. At first the heads of teasels were used but these were soon to be replaced by brass wire, though the term 'teasing' remained. (The demands of carding in the seventeenth century were, in fact, a great stimulus to the wire-making industry.) Washed raw wool was placed on the teeth of one carding board, and the other was repeatedly drawn over it in one direction, to disentangle the

fibres. To get the wool off the cards, one board was turned round and again passed over the other; the teeth being set at an angle, this stripped the wool off the card. Many examples of hand cards survive and may be seen in, for example, Dumfries Burgh Museum; Bankfield Museum, Halifax; and the Museum & Art Gallery, Peel Park, Salford.

Wool used for worsted cloth required rather more thorough treatment, for the fibres had not only to be laid parallel to each other but also unwanted short staple wool had to be removed. This process was called combing. Two hand combs with tapered wooden teeth were used. A small quantity of wool was placed in the teeth of one of the combs, which was held firmly in a bracket while the other was drawn over it, pulling more and more wool out and collecting the longer fibres in its teeth. When most of the wool had become caught in the hand-held comb, the two were changed over and the process repeated. After combing, the long fibres were collected and joined into long slivers known as 'tops', which were sent for spinning. The remaining short staple fibres, called 'noils', were sold for woollens. When spun, combed wool produced a smooth fine worsted yarn, much harder than ordinary woollen yarns. Combing presented considerable difficulties for mechanisation and was the last section of the wool textile industry to be hand-worked, remaining so until after 1850. Hand combs may be seen in the Art Gallery & Museum, Cliffe Castle, Keighley, and the Bridewell Museum, Norwich.

After carding or combing, both woollens and worsteds were spun and, although different techniques of manipulating the fibres were employed, both involved the same equipment and went through the same processes. Spinning twists the fibres around each other and draws them together to form a yarn suitable for weaving into cloth. The most primitive technique was to use a spindle and distaff, in which the distaff or stick carrying the wool was held under one arm, often supported by a leather belt around the waist of the spinster. Strands of wool were pulled from the distaff and attached to the spindle, a small stick with a weight at one end. The spindle was suspended from the wool, given a twist with the finger to set it spinning, and the wool paid out slowly. When a length of yarn had been produced, it was wound round the spindle, the end caught in a notch to prevent it unwinding when suspended, and the process repeated.

The spinning wheel, which probably originated in the Far East, was a

great improvement over the spindle and distaff and may be regarded as the first example of 'mechanisation' applied to the textile industry. In it the spindle was mounted horizontally in bearings and connected to a large flywheel by a driving band. This produced more consistent rotation of the spindle and speeded up the spinning process considerably. At first the large wheel was turned by hand, but later a treadle, connecting rod and crank on the wheelshaft were used—probably the first use of the common crank for developing rotary motion at least two centuries before Pickard and Watt 'rediscovered' it for the rotative steam engine. In the early type of spinning wheel known as the 'big wheel' or 'Jersey wheel' a piece of unspun wool was attached to the spindle and the large wheel turned by hand. The other hand holding the wool was pulled back slowly from the spindle paying out at a steady rate strands which were spun into yarn. When a length had been spun, the wheel was turned again to wind the yarn on to the body of the spindle. The process was then repeated.

Later a new type of spinning wheel, the Saxony wheel invented in 1555, largely supplanted the big wheel; it was an improvement as it both spun the yarn and wound it in at the same time, making the whole operation continuous. It was used for the spinning, usually of long fibres, until the late eighteenth century. The main section of the Saxony wheel was the U-shaped flyer that was attached to the spindle. The bobbin ran loose on the spindle shaft and was driven by a separate band from the flywheel. Thus yarn was spun continuously on the spindle and fed from the arms of the flyer to the bobbin rotating at a different speed. With all these methods of spinning, however, there was inconsistency of quality, as the results depended on the skill of the individual spinster, who had to pay out the right amount of wool to maintain an even thickness of yarn. As most of the women in a household learned to spin, this often meant that different qualities of yarn might be found even on the same spindle. This was an inconvenience to the weaver and an important incentive towards devising a machine that would produce consistent yarn. Spinning wheels are perhaps the most common evidence of pre-industrial textile manufacture to be found in museums today. In the Textile Machinery Museum, Tong Moor Road, Bolton, both Jersey and Saxony wheels are exhibited, and the Horner collection in the Ulster Museum, Belfast, contains spinning wheels from a number of countries.

Once a suitable yarn had been spun, the next process was to weave it into

a cloth fabric on a loom. The traditional hand loom consisted of a frame carrying the longitudinal or 'warp' threads, which could be separated to allow the transverse 'weft' threads to pass alternately over and under them. This simplest form of interlacing of warp and weft is known as plain weave and was for centuries carried out on simple hand looms. The main obstacle to speeding up the process of weaving was the problem of moving the shuttle containing the weft yarn wound on a bobbin across the loom between the alternate warp yarns. The answer, when it came in the form of the 'flying shuttle', was one of the crucial inventions of the textile industry; it was remarkably simple in principle, cost very little and led to an enormous increase in hand-loom weaving, an increase which was to have tragic repercussions in the 1820s. With the exception of the stocking frame, which produced a knitted as opposed to a woven fabric, and which will be considered later, it was to be the first move in the sequence of events leading to the fully mechanised textile industry.

From the industrial archaeological point of view the chief features to examine are the textile machines themselves, the prime movers that drove them and the buildings that housed machines and workers. Of the textile machines a reasonably representative range has been preserved in museums, mainly in Lancashire and Yorkshire, but the prime movers—the water-wheels and steam engines that powered those machines—are somewhat harder to find. The technology of these sources of power has been considered in Chapters 3 and 4, but there were variants specific to the textile industry, such as the steam mill engine, which are worthy of additional passing reference. It is in the buildings, however, particularly those dating from the middle of the eighteenth century onwards, that the most prolific archaeological evidence of the industry lies. Indeed, of all the landscape changes brought about by the Industrial Revolution, the textile mill building is one of the most prominent. The evolution of the textile mill, almost from its earliest days, can be traced through surviving examples, in some of which were incorporated important innovations in constructional technique. In examining the industrial archaeology of textile manufacturing we will look first at the development of the machine itself and then at the buildings and power sources.

As we have seen, the bottleneck in the hand-weaving process was the speed at which the weft threads could be passed through the warp. The

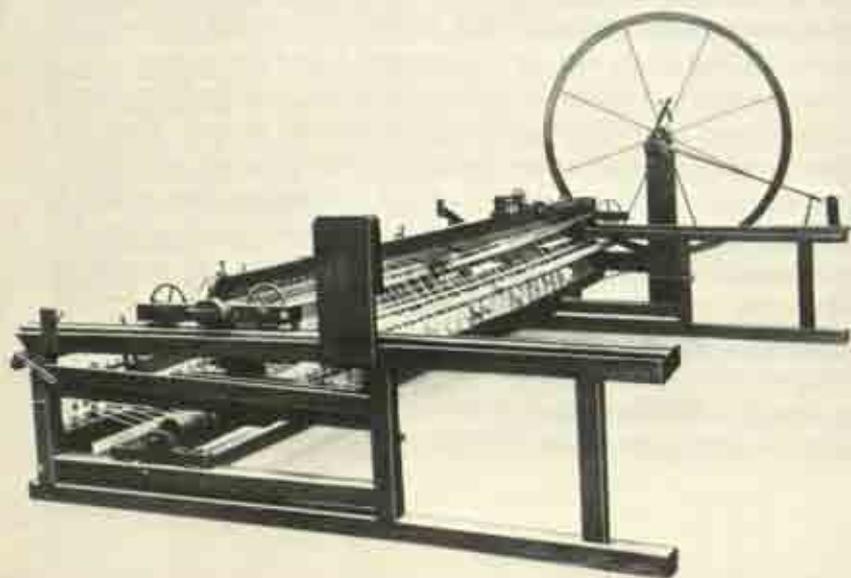
answer was found by John Kay (1704-1780) who was born at Park near Bury in Lancashire. He was apprenticed into the weaving machinery trade and spent the whole of his working life involved with textile equipment. His 'fly' or 'flying shuttle' of 1733 (Patent No 542) consisted of boxes to hold the shuttle at each side of the loom connected by a long board, or 'shuttle race', along which the shuttle ran. Each box had a horizontal metal rod, and on each rod was a freely moving slide known as a 'picker'. Each picker was connected by a string tied to a stick or 'picking peg' held by the weaver. By jerking the picking peg from side to side, the weaver could throw the shuttle from one shuttle box to the other. Kay fitted wheels or rollers to some of his shuttles but later these were discarded and the term 'flying shuttle' was used. The operation of weaving became not only less tedious but output was often doubled.

There were a number of minor technical difficulties that slowed down the adoption of Kay's flying shuttle, an initial disbelief in its workability and considerable unwillingness by many weavers to pay the 15s per year which he charged for the use of his invention. However, it was widely taken up eventually, and had the effect of speeding up weaving and thereby substantially increasing the imbalance between the weaving and spinning processes. Even before his invention, four or five spinsters had been needed to supply one weaver, and the flying shuttle still further increased the incentive to devise a machine that would spin more than one or two threads at a time. Numerous hand looms, with and without flying shuttles, may be found in museums specialising in textile machinery, including the Bankfield Museum, Halifax, where they are demonstrated from time to time.

The first attempts at the mechanisation of spinning were made by Lewis Paul (d1759) and John Wyatt (1700-66) and patented in 1738. Their first machine, involving pairs of rollers to draw out the fibres, was unsuccessful, as were a number of variations on it produced in succeeding years, although the roller drawing principle was eventually used with great success. An experimental mill was built in Birmingham about 1741 and another in Northampton, but neither appears to have been very successful. A skein of yarn produced on a Paul & Wyatt machine is, however, preserved in Birmingham Museum & Art Gallery, and the Avery Historical Museum at Soho Foundry, Birmingham 40, besides its collection of wool scales and weights, has some documentary information on the two inventors.

It was not until the 1760s that James Hargreaves (c1719-78), a weaver of Stanhill near Blackburn, where his cottage still survives (95/SD 728277), developed a successful mechanism for spinning cotton on multiple spindles—initially eight and later sixteen. This was the spinning jenny, a hand-operated machine that fitted well into the domestically based spinning industry. The term 'jenny' is a simple corruption of the word 'engine', as is the 'gin' used in 'horse-gin', a term used in mining and for the machine that removed seeds from raw cotton. In the jenny a hand-driven wheel powered a number of spindles, and a clasp drew out the spun yarn from each of them at the same time. Having completed the drawing out, the clasp moved forward and the spun yarn was wound on to the 'cop', which, when full, became a cylindrical package of yarn with conical ends. The jenny (Plate 45) was, in effect, a mechanised Jersey wheel, as the spinning process was not continuous; but because of the larger number of spindles which it employed, output was very considerable. Jennies to be seen in most museums are of the improved variety, with a large number of spindles, but Higher Mill, Helmsshore, in Lancashire (95/SD 777214), where a textile machinery museum is being established, has a jenny built a few years ago to the specification in Hargreaves'

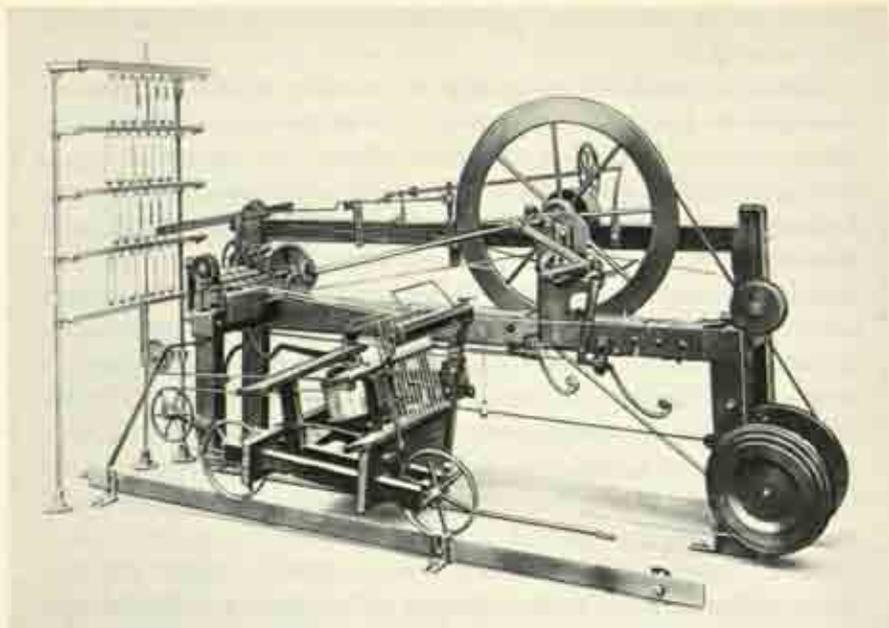
45 Multiple-spindle spinning jenny in Bolton Textile Machinery Museum



original patent. A visitor to Higher Mill can see this and other equipment demonstrated.

There was considerable antagonism in Lancashire towards Hargreaves as a result of his invention, so he moved to Nottingham, where demand for cotton yarn for knitting in the stocking-frame was growing. Here he established a mill and in 1770, several years after his invention of the jenny, he finally took out a patent for it. The fact that Richard (later Sir Richard) Arkwright (1732-92) had patented a new device for spinning in 1769 may well have prompted this action by Hargreaves. Certainly Arkwright's machine proved much more suitable than the jenny for producing the fine cotton threads needed in knitting. Yet in Lancashire jennies became more and more popular for the weft yarn of cotton-linen woven fabrics and for all-cotton goods. In the woollen industry, too, the jenny was found to be an efficient means of spinning soft full yarns. Equally as important was the fact that it was cheap and could be used by cottage spinners and small manufacturers alike.

Richard Arkwright was born in Preston, Lancashire, apprenticed to a barber and subsequently set up in business on his own as a barber and wig-maker. He became interested in mechanisms and the problems of a satisfactory spinning machine and, in association with a clockmaker in Leigh named John Kay (not associated with the flying shuttle inventor), Arkwright produced a prototype roller spinning machine for cotton. As with Hargreaves, hostility to Arkwright arose from those people already in the spinning industry who saw the machine as a threat to their livelihoods, so he too went to Nottingham and set up a business providing yarn for the knitting industry. He found a partner in a successful and well established hosiery manufacturer named Jedediah Strutt, and they established a small factory with a number of spinning machines driven by horse power. The yarns produced were most satisfactory for the hosiery industry, so in 1771 Arkwright moved to Cromford on the River Derwent in Derbyshire and there set up a larger mill driven by water power. As a result of the use of this source of power, Arkwright's roller-spinning device became known as the water frame. On it was based the enormous development of factory spinning and the further fortunes of its inventor, who built numerous other mills, was knighted and became High Sheriff of Derbyshire. Of all the pioneer inventors in textiles during the eighteenth century, Arkwright had



46 Spinning mule developed by Samuel Crompton. Bolton Textile Machinery Museum

the least propitious beginning and derived the greatest benefits. He can really be described as the father of the factory system, an outstanding organiser of labour and machinery processing, ambitious, forceful and persevering.

A still more important advance in eighteenth-century spinning technology was still to come, however. This was the invention of the spinning mule (Plate 46) in 1779, in effect a combination of the jenny and the water frame, hence the name 'mule'. Its inventor Samuel Crompton (1753-1827) was born near Bolton, Lancashire, and began spinning on a jenny as a boy. His mule (Fig 27) was a great advance on either of the machines from which it derived—if in fact Crompton had any detailed knowledge of Arkwright's invention—and was particularly suitable for making fine yarns for muslin. The first mules had about thirty spindles but soon 130 were common. By moving the driving wheel to the centre, it was possible to operate still longer mules, and 400 spindle machines were built. Later machines carried



Fig 27 Mule spinning (from *The Circle of the Sciences*, Vol II, 609)

more than 1,000. In 1792 water power was applied at New Lanark Mills (Plate 47) in Scotland (61/NS 880425) for the first time to drive mules and this established large-scale factory mule spinning. Crompton's house near Bolton, 'Hall-i'-th'Wood' (101/SD 724116), still stands and is now a museum of the Crompton family. The Textile Machinery Museum in 47 Robert Owen's model town of New Lanark



Tong Moor Road, Bolton, includes water frames, Crompton's mule and other early textile machines. Mules may also be seen at Higher Mill, Helmshore, where there is an original Arkwright water frame from his Cromford mill. A pre-industrial water-powered textile mill in regular operation and open to visitors is the Esgair Moel Mill from Llantwrtyd, Brecknockshire, re-erected at the Welsh Folk Museum, St Fagans (154/ST 118772), in 1951. Here too may be seen a spinning mule, with eighty spindles, together with three hand looms and all the other equipment to convert raw wool into dyed and finished fabric.

Throughout this period of rapid development on the spinning side of the textile industry the hand loom for weaving fabric had remained virtually static, although there was a progressive increase in the use of the flying shuttle. There had been powered looms since the sixteenth century for weaving silk ribbons, but the general opinion among fabric weavers was that the hand loom involved too many independent actions requiring timing and skill to mechanise. The first breakthrough came in 1784 with the invention by Dr Edmund Cartwright (1743-1823), a Leicestershire rector, of a loom which could be powered, although he had never at the time seen a person weave! Cartwright's loom was by no means sophisticated, all its actions being rapid and harsh, particularly that of the shuttle, which was propelled by a powerful spring. Its main contribution was to prove the feasibility of powered looms, and other inventors were stimulated into carrying out further experiments. Cartwright looms of a more highly developed type were in use in Doncaster and Manchester in the 1790s, while in Scotland numerous inventors, including Robert Miller and J. L. Robertson of Glasgow, made improvements. The most significant improvement, however, was devised by William Horrocks of Stockport, who in 1813 introduced a means of varying the speed of separation of the warp threads so as to increase the period for the shuttle to pass through.

Between 1813 and 1820 the number of power looms in Britain increased from 2,400 to 14,150, but even then the bulk of woven cloth was still being produced by hand-loom weavers. The largest spinning mills employed 1,500 people, and almost all the preparatory processes, like carding, had been mechanised for wool and worsted, cotton, silk and flax. By 1820 there were 110,000 workers in spinning mills, but only 10,000 in weaving factories, and some of them were working traditional hand looms in factory buildings. As

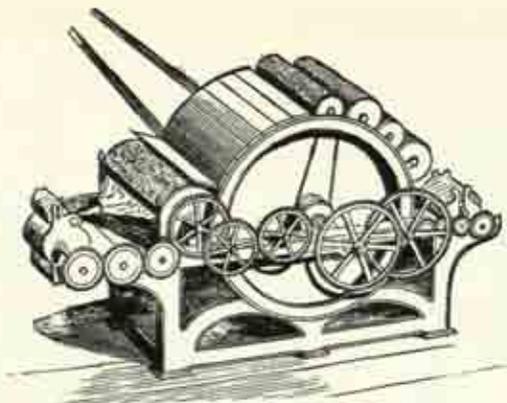


Fig 28 Carding-engine for cotton (from *The Circle of the Sciences*, Vol II, 607)

power looms began to be improved mechanically, their numbers increased rapidly, so that the 2,000 looms per year installed between 1813 and 1820 had become 10,000 a year by the 1830s. Meanwhile the hand-loom weavers sank from being among the most prosperous workers in the country to some of the most poverty-stricken. The weavers' skills were no longer required, as in the factories the simple work of mending thread breakages and replenishing shuttles could be carried out by women and children. In the 1810s, first in the Midlands and subsequently in Lancashire and Yorkshire, the machine-smashing Luddites responded to these conditions, made all the more appalling by the general depression after the Napoleonic wars.

In other branches of the textile trade mechanisation took place during the late eighteenth and early nineteenth centuries also. At the preliminary processing end, carding machines (Fig 28) were developed by a number of inventors; most worked on the roller principle, in which a large cylinder with wire teeth took the fibres round under a series of smaller 'worker' rollers running at a different speed, and they did the carding. Although these early carding machines were developed for cotton (Fig 29), it was not long before they were applied also to wool, where they were called 'scribblers'. Pattern weaving was also greatly improved after about 1800, with the introduction of the Jacquard attachment in which individual warp threads were lifted by a mechanism mounted above the loom and controlled by punched cards. The type of pattern depended on the 'programme' punched into the continuous strip of cards.

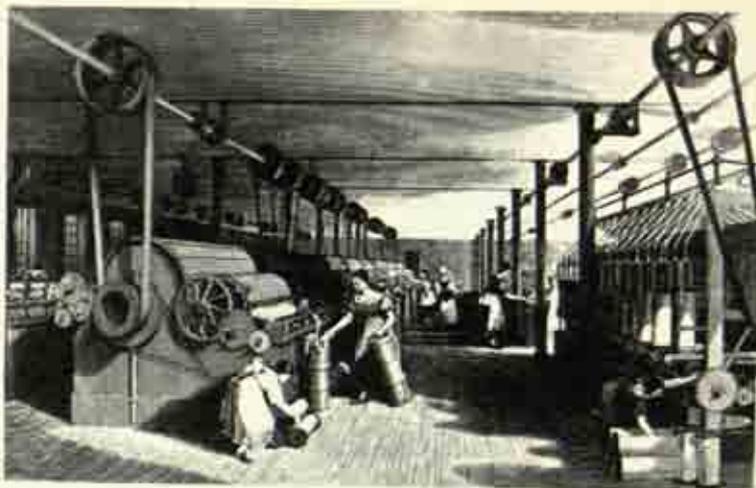


Fig 29 Carding, drawing and roving (from *The Circle of the Sciences*, Vol II, 608)

In the hosiery manufacturing industry, in which stockings were knitted by the looping together of threads to form an elastic fabric, the basic machine, the knitting-frame, had been developed as early as the 1590s by the Rev William Lee of Calverton near Nottingham. It was one of the most ingenious inventions in the textile industry and formed the basis for the early rise of the East Midlands as a hosiery area. The problem was one of looping threads into each other using a hooked needle, and the answer lay in developing a way of opening and closing the hook automatically to allow the loop to be made and the needle to be disengaged and then withdrawn without re-engagement. The crux of Lee's invention lay in a hook which was normally open but could be closed by pressure. By filing a slot in the shank of the needle, the point of the hook could sink into it upon closure and thus avoid any accidental catching of the loop. This is the bearded needle widely used in knitting machines today. A further development came with the mechanisation of rib knitting in 1758 by Jedediah Strutt. Rib-knitted hosiery was more closely fitting than plain-knitted but at the same time more elastic. Strutt's invention consisted of an additional set of needles added to the conventional stocking-frame which, operated in conjunction with the usual needles, had the effect of reversing the loop and producing a rib effect. A more fundamental development came in 1775 when the first warp knitting-

machine was introduced. Previously loops had been formed in threads running across the width of the fabric (weft knitting), but the new machine, attributed to both J. Crane and J. Tarrett of Nottinghamshire, produced a knitted fabric which could be cut up and sewn into garments. By the 1850s rib knitting was being produced on powered circular machines, thus producing a tubular fabric for stockings, and about the same time M. Townsend of Nottingham patented the 'tumbler' or 'latch' needle, which was to be fundamental to the further progress of the knitting industry. Generally similar in appearance to the bearded needle, the latch needle had a hinged attachment to open and close the hook. All these and many more aspects of the technology of knitting can be seen in the large collection of machines held by Leicestershire Museums and on display at the Newarke Houses Museum, Newarke, Leicester.

Similarly the lace industry, so important in and around Nottingham, is well represented by machines on display at Nottingham Industrial Museum, Wollaton Hall, Nottingham. The basic step in the mechanisation of lace making had been made by John Heathcoat (1783-1861) in 1809, when he developed a machine (the bobbinet, later known as the plain net machine) capable of imitating almost exactly the hand-made pillow lace. He used a flat bobbin, resembling a disc, which could pass between the vertical warp threads and thus entwine the weft thread around them. In 1813 his machine was improved by John Lever, who adapted it to make patterned lace, using, if necessary, the Jacquard principle.

One major aspect of fabric production that has still to be considered is the finishing of the woven cloth. One of these finishing processes had been mechanised as early as the thirteenth century, when water-powered 'fulling' mills had replaced manual fulling of wool cloth. The process consisted of pounding the woven fabric in water with fuller's earth to felt it up and shrink it. It was relatively simple to devise water-powered hammers to carry out this work, cams on a shaft raising the heads in much the same manner as the tilt hammers used for ironworking. The effects on location of the industry were similar, too, resulting in an essentially urban-based craft moving out and dispersing to the fast-flowing streams of north Somerset, central Gloucestershire and west Wiltshire in the South West, and from towns like Beverley and York to the Pennine streams of the West Riding of Yorkshire. A number of fulling mills still survive and at Higher Mill, Helmsshore



48 Higher Mill, Helmshore, Lancashire. An iron breastshot waterwheel with peripheral gearing and wooden floats

(95/SD 777214), the waterwheel (Plate 48) and fulling stocks can also be seen, as can the tenter hooks on which the cloth was subsequently stretched and dried and the rotary gig-mills containing teasels, which were used to raise the nap on the cloth. This was afterwards sheared, first by large hand-shears and later by a rotary device in action very similar to a cylinder lawnmower.

#### THE FIRST FACTORIES

The factory system that developed so rapidly in the textile industries at the end of the eighteenth century had its origins in 1702. In that year Thomas Cotchett (b1640) opened a three-storey silk spinning mill on the River Derwent in Derby in which he installed Dutch spinning or 'throwing' machinery. Although Cotchett's business failed and all but a few of the foundation arches of his building have disappeared (121/SK 354365), his mill has a good claim to the title of the first factory in that it was a single building with complex machinery, a source of power in its waterwheel,

and accommodation for a number of employees. What was perhaps of more immediate importance was that his enterprise attracted the attention of the wealthy London silk merchant Thomas (later Sir Thomas) Lombe (1685-1739), and his half-brother John Lombe (1693?-1722), who worked for a time in Cotchett's Mill. Some years later, possibly after a visit to the highly advanced silk spinning areas of Italy, the Lombes built a much bigger factory in Derby near Cotchett's original building.

Here the three basic operations of converting the silk filament from the cocoon of the silkworm into a yarn suitable for weaving were carried on. The first stages, carried out before the silk arrived at the factory, consisted of unwinding the filament from the cocoon and rewinding it with others to form a skein. This skein was washed to remove the gummy matter known as sericin and was then ready for processing in Lombe's factory. Here it was wound on to bobbins on a winding machine; transferred to a second machine where the strands from several bobbins were wound on to a single bobbin, a process known as 'doubling'; and finally twisted together into a yarn on a third machine, a process known as 'throwing'. If the yarn was to be used for the weft in weaving, only a slight twist was put into it, but if for the warp, a stronger twist was applied. The weft yarn was called the 'tram' and the warp the 'organzine'.

The Lombes' factory in Derby was of unprecedented size, the throwing mill alone being five storeys high and 110ft long and accommodating over 300 workers. These were mainly women and children who reknotted the threads when they broke, a very frequent occurrence. A single large water-wheel operated over 25,000 movements in the machinery. The building established the form the textile mill was to take until well into the twentieth century, the name 'mill' itself deriving from the fact that all the early ones were water-powered. It remained in active use for silk until 1890, when part collapsed, and after a disastrous fire in 1910 the building was substantially altered. Today the original approach bridge and part of the tower survive, together with foundations in the river bank. The wrought-iron gates, dating from 1722, were re-sited in 1934 near the Borough Library in Wardwick, Derby.

Why the industry became established in Derby is difficult to explain. The main centre, occupied largely by refugee Huguenot weavers, was in the Spitalfields area (Plate 49) of London where, in and around Fournier Street



49 Silk weavers' garrets in Spitalfields, London

(160/TQ 338818), a considerable number of their houses with attic workshops still survive. The rise of the Nottingham framework knitting industry is the most likely reason for Cotchett and the Lombes coming to the East Midlands, and Derby may well have been chosen because of the power afforded by the waters of the Derwent. The Trent itself and tributaries like the Leen and Erewash would have been quite unsuitable. From Derby the silk industry spread to other centres after the expiration of the Lombe patent in 1732, and factories were established initially in Macclesfield, Stockport and Chesterfield, and later in Manchester, Salford, and Braintree in Essex where George Courtauld and his son Samuel founded the firm which is now world famous for man-made fibres.

In the first half of the eighteenth century, however, the silk industry's growth rate was relatively slow and, despite the fact that factories had been established, it played no part in the large-scale industrial progress in textiles that came later with cotton and wool. The reasons for this were the shortage



50 Silk weavers' houses in Macclesfield, Cheshire

of raw silk supplies, which were also expensive, and the competition from continental and eastern silks abroad, which destroyed the chance of appreciable export markets. The cotton industry on the other hand enjoyed unlimited supplies of raw material and, once the plantation system had developed fully in the American South, supplies that fell in price. Cotton fabric, an attractive and cheap alternative to wool, was able to penetrate the enormous and growing home market and at the same time, as a result of the fall in costs and prices as a result of technological innovations in the industry, to enjoy an almost unlimited export market. Cotton was also a tractable fibre lending itself to machine processes more readily than wool. Finally the cotton industry, for reasons which we shall examine shortly, had the good fortune to establish itself in Lancashire, which was not a traditional textile area and had none of the built-in restrictive practices to be found elsewhere. Thus it was cotton which stood in the forefront of industrial progress in the textile industry despite the fact that what might be called the first generation of true factories were for spinning silk.

## THE DEVELOPMENT OF THE FACTORY BUILDING

The early silk mills and Arkwright's first cotton mills at Cromford were characterised by the fact that they contained novel machinery in buildings of essentially traditional construction. All the ingenious devices developed to convert fibre into cloth were of a size suitable for arrangement in rows watched over by relatively unskilled operatives. Eventually all could be powered from a rotating shaft that had at its input end a horse-gin in a few early examples, but more often a large waterwheel, and increasingly after about 1800 a rotative steam engine. The requirements of the factory were therefore large numbers of identical spaces, with reasonable natural lighting, arranged in such a way that power could easily be distributed to the machines. The outcome was a new form of building, taking the traditional constructional techniques of brick or stone load-bearing walls and timber beam-and-plank floors as its basis. Typically it was long and thin in plan, rarely more than 40ft deep, rising to four to six storeys, and with the line-shafting to carry power to the machines arranged parallel to the long axis and supported at or near ceiling height. This was basically the form the Lombes' mill had taken in 1721, and it was to survive virtually unaltered for two centuries.

Numerous fine examples of early textile mills still exist, although unfortunately Arkwright's Old Mill at Cromford (111/SK 298569), completed in 1772, has been so substantially altered, with the loss of two storeys, that it is almost unrecognisable. Masson Mill (111/SK 294573), however, built in 1783, is largely intact, the red-painted walls and white window surrounds a familiar feature on the A6(T) north of Cromford (Plate 51). Arkwright was associated with a number of other mills which, like those at Cromford, were located on streams that could provide power. At Cressbrook (111/SK 173728) the remains of his 1779 mill can be seen at the west end of the existing 1815 building, the latter a superb four-storey structure built by William Newton (Plate 52), one of the finest examples of the adoption of an enlarged domestic style for mills. It has twelve bays with a centrally placed four-bay pediment, hipped roof and a cupola that once held a bell to summon the workers.

An even finer example of this Georgian style may be seen in a number of silk mills in Macclesfield, notably Frost's Mill (110/SJ 918737) in the centre of the town (Plate 53) and the former silk mill on Chester Road, now the



51 Arkwright's Masson Mill, Cromford, Derbyshire

card factory of Henry and Leigh Slater (110/SJ 909737). This latter building epitomises the large eighteenth-century mill—a rectangular and disciplined brick box for machinery obeying to the letter the architectural rules of the day. The Macclesfield card factory has four storeys and seventeen bays, the centre five brought forward and supporting a pediment with central clock, cupola and wind vane. In Hampshire the same style on a much smaller scale can be seen in the beautiful red brick Witchurch silk mill (168/SU 464481), while in Cheshire, Quarry Bank Mill, Styal (101/SJ 834830), built in 1784 by Samuel Greg of Belfast on a more complicated plan, has the same graceful rhythm. A number of features typical of most of these early mills are worthy of examination. Firstly the windows, which have small panes and are usually of the sash type, often have cast-iron frames. Generally speaking



52 Cressbrook Mill, Derbyshire, a cotton mill of 1815 with later weaving sheds in front

the smaller window panes are the earlier, good examples being found at Calver Mill, Derbyshire (111/SK 245744), and Low Mill, Caton, in Lancashire (89/SD 527649). In the latter case the mill was built originally in 1784 and rebuilt after a fire in 1838, probably with the original windows. Tie irons of a disc or cruciform shape also are frequent, and in many cases appear to date from the construction of the building. These wall plates are tied by wrought-iron rods that pass right through the building and hold it together.

Inside, the floors consist of timber beams and boards sometimes supported by vertical timber pillars but more often by cast-iron ones of circular or cruciform section. The position of original line-shafting, if it has gone, can usually be traced from the positions of brackets or bracket-fixing holes either in the columns or on the ceiling beams. Occasionally the column itself is forked or has a bracket fixing cast on to it to support the bearing or 'plummer'

53 Frost's Mill, Macclesfield, Cheshire, like a number of other silk mills in the town, epitomises the translation of the Georgian domestic vernacular into the new textile factories



FROST'S YARNS

block. The position and size of watercourses are also worth noting, as they given an indication of the type of waterwheel used. In early mills the wheel was often centrally placed in the building with a vertical timber shaft taking the drive from the pit wheel up through the building to engage the horizontal line-shafts on each floor. Later, iron shafts and gearing were used. In smaller mills the waterwheel might be outside the building altogether, either completely exposed or housed in a small lean-to.

Although the general form of the multi-storey textile mill had been established at the beginning of the eighteenth century, a fundamental change in its technique of construction evolved in the 1780s and 1790s as a result of what we might now call a research programme. Arkwright's major partner in his Cromford venture was Jedediah Strutt, who had substantial silk interests in Derby and, after the dissolving of the partnership in 1781, took over completely the mills at Belper and Milford. These were greatly extended during the 1790s by Jedediah's son William Strutt (1756-1830), who systematically set about finding an answer to the problem of fire in these timber-floored buildings. Fires were frequent and usually disastrous, the complete destruction in 1791 of the enormous Albion flour mill in London providing the final incentive towards devising a solution. The first stage was reached in Strutt's calico mill in Derby, 1792-3, in which the floors were made of shallow brick arches of 9ft span springing from timber beams supported on cast-iron columns. The underside of the timber was coated with plaster to ensure that no surface that might catch fire would be exposed. Strutt produced more advanced versions at Milford in 1792-3 and Belper in 1793-5, but it was in fact a friend, Charles Bage, who took the next step by replacing the timber beam with a cast-iron one, so producing the world's first iron-framed building, a flax mill in Shrewsbury (118/SJ 500140). Although all Strutt's early buildings have now gone, the Marshall, Benyon & Bage flax mill, now used as a maltings, still stands at Ditherington, Shrewsbury. The modern factory had arrived and, although it was to be more than another 50 years before it became a completely frame structure and the load-bearing exterior walls disappeared to be replaced by curtain-wall cladding, the Shrewsbury flax mill must be regarded as one of the pioneer structures of the Industrial Revolution. Others quickly followed and, although the immediate descendants have been destroyed, Strutt's own response to the Bage building, his North Mill at Belper (111/

54 Anglo-Scotian Mills,  
Beeston, Nottingham



SK 346480), completed in 1804, still survives as the most beautiful, sophisticated and technically perfect structure of its era. Now owned by English Sewing Cotton Ltd, the mill is still in use and likely to remain so.

While these giant cotton and flax mills were developing so rapidly in the early years of the nineteenth century, the wool textile industry was stirring, too, although less violently. In the Stroud valleys of Gloucestershire numerous mills, most of them relatively small, were being built in the warm local stone, usually with interiors of conventional timber construction. Similarly in west Wiltshire and north Somerset water-powered wool mills appeared in considerable numbers. An exception to all the others is Stanley Mill at Stonehouse near Stroud (156/SO 814043), which is of

cast-iron and brick 'fire-proof' construction. Built in 1813 to draw its power from the River Frome, Stanley Mill provides a remarkable combination of the functional use of brick panels and stone pilasters on its outside with traceried iron arches supporting iron floor beams on iron columns. By the 1820s the iron-framed textile mill had become well established, although it was not until the 1860s or even later that the building of mills with timber beams and floors died out. One reason may have been the failure of a number of cast-iron frame structures, such as the celebrated collapse of Lowerhouse Mill, Oldham, in 1844, and another the appreciation that, although iron itself was incombustible, if a fire did occur in an iron-framed building, the expansion of the members frequently resulted in the destruction of the shell of the building too.

It was to Lancashire that the cotton industry migrated in the late eighteenth and early nineteenth centuries, and there the factory continued to evolve. Large numbers of these buildings still survive, offering the industrial archaeologist an opportunity to examine in detail their evolution. Initially water, for power, washing and bleaching, was the major locational factor, with the result that mills tended to be situated in remote valleys of the Pennines where such site advantages outweighed problems of communication. With the introduction of steam power, however, new factors influenced location and the cotton industry became concentrated in towns stretching from Stockport in Cheshire north to Preston. These new cotton towns grew up on the Lancashire plain, still enjoying the water necessary for various finishing and bleaching processes, but having easier access to Liverpool for raw materials, to Manchester for marketing the finished products, to coal, and by virtue of the concentration of large numbers of mills to pools of skilled labour both for operating and maintaining the machinery.

An important example of this first phase of steam-powered mills survives in Orrell's Mill, Travis Street, Heaton Mersey, Stockport (101/SJ 867903), built in the mid-1830s by William (later Sir William) Fairbairn (1789-1874), the celebrated Manchester engineer. The mill has six storeys and the main spinning rooms are 280ft long by 50ft wide. Cast-iron columns and beams support the floors. Numerous less spectacular examples can be found in most of the textile towns, simple in shape and design, with rectangular windows regularly spaced and separated by almost their own width of

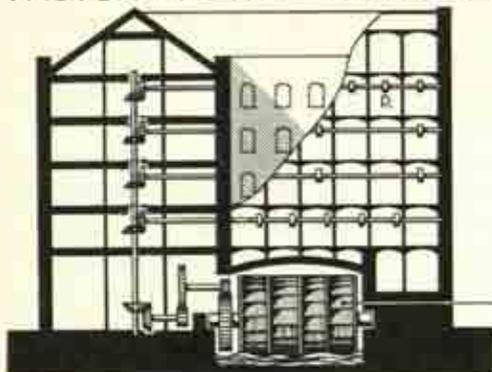
brick wall.

From the 1860s onwards, and particularly after the widespread adoption of the American ring-spinning frame, cotton mills became much larger and were typically built of dark red brick with progressively increasing areas of glazing. The introduction of sprinkler systems for fire control necessitated high-level water tanks, which were at first simply placed on the roof of the mill, as at the 1851 Galgate silk mill at Ellel (94/SD 485557). By the late 1870s, however, it was more common to enclose the tank within the structure of a tower that frequently bore the name of the mill in white tile lettering.

The gradual recovery of the Lancashire cotton industry after the devastating effects of the American Civil War led eventually to a new boom in building, which, between about 1880 and 1920, brought the cotton mill to its ultimate state of development. Enormous brick-built spinning mills, often in shiny red Accrington brick with yellow brick detailing, great expanses of glass and highly ornamental towers, were built in large numbers, and they still dominate the skyline of most towns between Preston and Oldham. The demand created by large machinery for bigger and bigger spaces with fewer intermediate supports was satisfied by new constructional techniques employing initially fabricated wrought-iron beams and later, as at Centenary Mill, Preston (94/SD 551297), built in 1895, rolled steel beams and concrete floors. Less load was carried by the external walls, which in many cases became almost entirely glass, the brickwork being reduced to little more than mullions between large glazed panels. All-concrete construction was slow to be adopted in Britain, although it rapidly reached an advanced state of development abroad, notably in France. Concrete, however, was to bring the all-glass wall to the textile mill, one of the results of mushroom construction in which concrete pillars set well in from the skin of the building supported the floors on the cantilever principle. A good example is the Viyella factory designed by F. A. Broadhead on Castle Boulevard, Nottingham (112/SK 570394).

In parallel with the evolution of the mill's shape and structure came important changes in power transmission. The earliest water-powered mills had used timber millwork, transmitting the power by wooden shafts and gearing. In the latter part of the eighteenth century cast-iron shafting and gears were introduced, to be superseded by lightweight wrought-iron shafts revolving at higher speeds which were developed first by Fairbairn in the

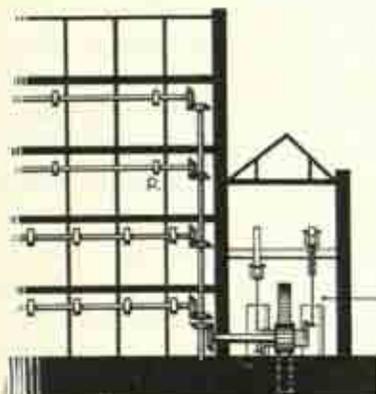
# FACTORY POWER TRANSMISSION



Water-powered textile mill c 1800 - shafts and gearing

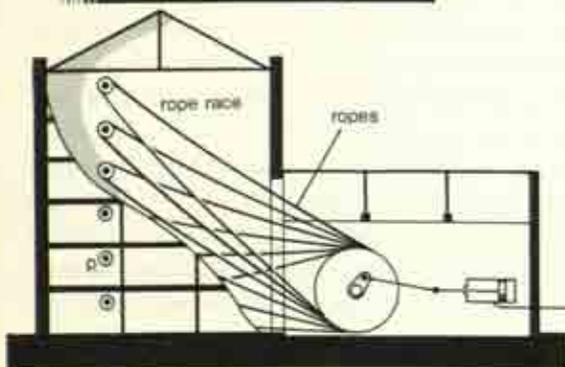
p. pulleys for machine drive belts

18ft diam x 30ft wide breast wheel



Steam-powered mill c 1850 - shafts and gearing

2 beam engines driving a toothed flywheel



Steam-powered mill c 1870 - cotton ropes, pulleys and lineshafts

horizontal steam mill engine driving a grooved flywheel

Fig 30

late 1820s. The greatest single advance came in the 1860s, when shaft drive was dispensed with altogether and ropes driven from the flywheel of the steam engine ran to each floor of the mill (see Fig 30). The flywheel face was grooved to take as many as thirty cotton ropes, which ran up through the rope race to drive the line-shafts at each floor. Ropes were mechanically efficient, cheap to install and maintain, and if a breakage occurred, the whole mill did not have to suspend production, as it did when a fault arose in a shaft-driven system. A specific type of engine evolved, too, in the steam mill engine, which became widespread in both Lancashire and Yorkshire. It was usually a horizontal compound with a variety of cylinder configurations (see Chapter 4 and Fig 14). A superb mill engine is preserved by the Northern Mill Engine Society at Dee Mill, Shaw, near Rochdale (101/SD 945093). Nearby is that other typical feature of all large steam textile mills—the pool, or mill 'lodge', in which condenser water was cooled and stored.

Although the spinning side of the textile industry produced a large and very individual style of mill building, the weaving of yarns into fabric resulted in an equally distinctive if less spectacular type of structure. Typically weaving was carried on in a single storey building, although in earlier mills looms occupied the ground floors of multi-storey spinning blocks. A good example of a weaving shed stands in front of Cressbrook Mill, Derbyshire (111/SK 173728), its roof of ridge-and-furrow form, with glazed north-lights on the steep-pitched faces and slates on the shallower sides. Wooden roof trusses with cast-iron columns were almost universal for weaving sheds, the looms being arranged in lines between the rows of columns on which line-shafts were carried. North-east Lancashire in particular abounds in weaving sheds mainly built in the latter part of the nineteenth century, when weaving became a speciality of towns like Nelson and Colne, Burnley, Blackburn, Preston and Clitheroe. In many ways the weaving shed, with its large ground floor area and good all-over lighting, formed the basis for the modern factory building to be seen on every inter-war trading estate and New Town.

On the east of the Pennines the early period of mill building, until, say, 1830, was generally similar to that on the west, although stone was almost universal as a building material. An early exception was Gott's Mill, Leeds (96/SE 291335), a large complex consisting of spinning mills and weavers' dwellings which was unfortunately demolished in the 1960s.

Just as exceptional, although for completely different reasons, was another Leeds mill, which happily still exists: Marshall's flax mill (96/SE 295326), completed in June 1840, is based on the Egyptian temple of Karnak. Designed by Bonomi and David Roberts, the single-storey preparing and spinning mill stretches 132yd along Marshall Street, and is 72yd in depth. The interior room of the Temple Mill, as it became known, covers some 2 acres, and slender cast-iron columns (which also act as drainpipes) support a ceiling 21ft high which has over 60 conical glass skylights 14ft in diameter rising above the roof. Along the façade stand squat columns flanking the windows, and supporting a massive Egyptianesque entablature, and to the north, set back slightly from the street line, is the office block added in 1843. The original chimney, built rather after the style of Cleopatra's needle, cracked in 1852 and was replaced by a conventional one. John Marshall (1765-1846), who built the Temple Mill and was also involved in the Shrewsbury flax mill of 1797, established his linen industry in Leeds in the early 1800s. The peak of its prosperity was exemplified by his Egyptian adventure of the 1840s but later, under a second generation, the business declined, to end finally in 1886. Temple Mill is now used by a mail order firm.

Two great complexes in Bradford epitomise the West Riding's position

55 The mill at Saltaire, Titus Salt's model village near Bradford, Yorkshire





56 Manningham Mills,  
Bradford, Yorkshire, built by  
Samuel Lister in the 1870s

57 The main entrance of  
Manningham Mills



in the textile industry in the second half of the nineteenth century, although, curiously enough, neither was concerned specifically with wool at the outset. Best known is Saltaire, the planned village surrounding mills, created by the model employer, social improver and philanthropist, Titus Salt (1803-76). Salt was born in Morley, near Bradford, and grew up in the worsted industry in partnership with his father at a time when the West Riding was beginning to outstrip the traditional centre of worsted manufacture in Norwich. His considerable business and inventive abilities enabled him to set up on his own, and by 1836 he owned four mills. His success in spinning the fibres of the South American Alpaca goat, previously regarded as unusable, led to a great increase in business at a time when a wide variety of differing warp and weft threads were being experimented with. By 1851 he had started a large new factory (Plate 55) on the River Aire outside Bradford around which he also built the new settlement of Saltaire, with its neat rows of houses for employees. By the 1870s a church, hospital, baths and schools had been added to form the complete model village which survives, virtually unaltered, today, a stage in the progress from New Lanark to Port Sunlight and Bournville.

The other major Bradford mill was built by Samuel C. Lister (1815-1906) at Manningham (96/SE 146348) and dates from 1873. Lister was an inventor and improver of processes, taking out more than 150 patents during his lifetime. Starting in the worsted industry, his major contributions included processes for combing wool and utilising waste silk, and it was on the strength of this latter technique that the great Manningham Mill complex developed (Plates 56 and 57). Velvet and plush were the main products which resulted from Lister's improvement of a Spanish loom for weaving pile cloth. The mill itself consists of two large six-storey blocks each capped by an ornamental and panelled parapet, and a series of lower buildings principally devoted to weaving. In the centre is the boiler house with a tall chimney resembling an Italian campanile.

## 11 The Chemical Industries

THE chemical industries present the industrial archaeologist with even greater problems than the engineering machinery discussed in Chapter 7, and for generally similar reasons. Not only are the processes of the industry fairly complex but the structures surviving from its past are often difficult to identify in the field. The very wide range of processes and plant can best be appreciated by reference to early textbooks on the subject like G. Martin's *Industrial Chemistry* (1925). The landscapes created by massive concentrations of chemical plant, in places like Widnes, for example, are among the most unattractive imaginable and, for this reason, derelict buildings and old waste tips of toxic materials are among the first to be removed in the interests of tidiness and public safety. An added difficulty results from the fact that the products of the chemical industry are rarely ends in themselves but are the raw materials for other manufacturing processes. The industry's evolution has therefore been governed by the demands of other industrial activities—of textile manufacturers for bleaches and dyes, of glassmakers for soda and of the fertiliser industry for sulphuric acid. To produce these chemicals, the industry demanded a wide variety of organic and inorganic raw materials, ranging from seaweed for alkalis and exotic foreign hardwoods for leather dyes to salt, copperas (derived from iron pyrites) and alum. Coal, besides providing the basis for town gas, was also an important raw material for many chemicals, although its main significance was as a fuel and as such an important factor in the location of chemical processes depending on heat. More recently oil has become an important, perhaps the most important, chemical base, its use extending back a surprisingly long way. Scottish oil shales were once the most important home source, but the vast quantities now used for fuel and chemical manufacturing purposes will nearly all continue to be imported until North Sea oil comes ashore in any quantity.

The varied nature of the chemical industry and its many products make systematic classification and examination difficult. Organic and inorganic raw materials were used, alkalis and acids were produced, and furnace techniques involving fusing and vitrification, evaporation resulting in crystallisation, and distillation were its most important processes. Two

of the most industrially significant furnace processes of what is in essence part of the chemical industry, the manufacturer of pottery and of glass, have already been considered in Chapter 9, so it is primarily with crystallisation and distillation that we are concerned in this chapter.

#### SALT

Common salt, sodium chloride, has long been and still is an important raw material for many chemical products, although for centuries before the Industrial Revolution its extraction, mainly by evaporation, was geared to its sale as an end product in its own right for direct human consumption and for the preservation of fish and meat. Although solar evaporation was used to a limited extent in medieval times, only at Lymington in Hampshire was the technique practised in relatively recent years: there for about 16 weeks in the summer seawater was concentrated into a brine solution in evaporation ponds known as 'salterns' before being boiled in lead or brass pans to extract the crystalline salt. From September the brine obtained during the summer was evaporated, using Newcastle coal brought in by sea, an expensive process only made economic by the saving resulting from solar evaporation and the large nearby market of the Royal Navy at Portsmouth, which needed salt for preserving beef and pork on board ship. The Lymington salt industry reached its peak of production in the mid-eighteenth century, when 50,000 tons a year were being produced, and finally closed in 1865. The low banks that surrounded the evaporation pools can still be seen on Keyhaven and Pennington marshes (180/SZ 315923). Similar circular banks exist at Crosscanonby, near Maryport (82/NY 066401). Saltworkers' cottages stood nearby till recently.

The other main areas of salt extraction from seawater were the Firth of Forth, the Ayrshire coast around Saltcoats, and the estuary of the Tyne and the nearby coastal areas of Northumberland and Durham. The availability of cheap coal was a major locational factor, only the poorest quality slack, which was not worth the cost of transport far from the pithead, being used. It was often known as 'pancoal'. The process was carried out in heated pans made initially of lead but later of iron in which the water was evaporated until the salt crystallised, leaving behind a solution of calcium and magnesium salts known as 'bitterns'. In some areas, such as Lymington, the bitterns formed a profitable by-product in the form of Epsom salts, 4-5

tons being produced for every 100 tons of common salt. In Northumberland, Seaton Sluice (78/NZ 336768) was developed as a coal and salt port in the seventeenth century, and on the Firth of Forth east of Edinburgh the ancient salt centre of Prestonpans (its name derives from the process carried on there) continued seawater salt extraction down to 1959.

The discovery of rock salt in Cheshire about 1690 and on Teesside in 1863 provided the foundation for the modern British salt industry and the chemical processes based on it. Initially salt from natural brine wells had been evaporated in the Northwich and Middlewich areas of Cheshire, and near Droitwich in Worcestershire. The 'wich' place name ending is a strong, but not infallible, clue to the existence of a salt industry. The extensive mining in Cheshire—the great Marston Mine north of Northwich (101/SJ 6760) produced 110,000 tons in 1882—gave way to brine pumping, in which water was circulated through boreholes sunk into the salt deposits and brought back to the surface as a solution from which the salt could be evaporated or, more recently, used in the chemical industry direct. Evidence of the extensive subsidence caused by salt working can be seen around Northwich in the form of extensive pools or 'flashes', and to the east of the town are brine wells (110/SJ 7471). There is now only one active salt mine, at Winsford. South of Middlewich the main Crewe to Manchester railway line suffers constantly from the sinking of the ground surface above salt workings. Some of the finest surviving structures of the salt industry are in Winsford itself (110/SJ 599997). They are the timber sheds used for drying salt, and their construction, which is entirely of timber as metal fittings would corrode in the salt-laden atmosphere, provides an interesting example of the timber-framed tradition of domestic building carried through into industrial structures. To the north of the town at Winnington (110/SJ 6474) is the plant set up in 1873 by Ludwig Mond (1839-1909) and John Brunner (1842-1919) to produce synthetic soda by the Belgian Solvay or ammonia process. This largely replaced the Leblanc process discussed below. Brunner, Mond & Co Ltd became one of the four largest chemical manufacturers in Britain, and in 1926 amalgamated with the other three—The United Alkali Co, the British Dyestuffs Corporation and Nobel Industries—to form Imperial Chemical Industries. Winnington is the headquarters of the ICI Alkali Division and is well placed for supply of its basic raw materials of salt, limestone and coking coal.

## SOAP

The growth of the wool and later cotton textile industries created new demands for soaps, bleaches, dyes and the mordants which fixed them. The two main types of soap used for cleaning fleeces and cloth were mixtures of fats or oils with mild alkalis, hard soap employing the alkali sodium carbonate (soda) and soft soap the alkali potassium carbonate (potash). These materials were boiled together for long periods to emulsify the ingredients, so a fuel, usually coal, was an additional requirement. From the thirteenth century onwards Bristol became an important soap-making centre based on the coincidence of local coal supplies and the great wool-producing areas of Gloucestershire, Somerset and Wiltshire. So important was the industry that the medieval writer Richard of Devizes wrote: 'At Bristol there is no one who is not, or has not been, a soap maker.' Today the industry in Bristol is extinct, although its major industrial monument—the exotic brick-built factory of Christopher Thomas & Brothers, makers of Puritan soap, at Broad Plain in the centre of the city (156/ST 597728)—dates only from the 1880s. The building, now used for storage, is one of the small collection of surviving structures which represent that curiously Bristolian style of commercial architecture, sometimes known colloquially as 'Bristol Byzantine', of the 1870s and 1880s.

Before the soap industry could reach an industrial scale of production, the problem of its raw materials had to be solved. Soda and potash were obtainable from the ashes of wood and seaweed and both were also increasingly in demand from glassmakers. Salts of sodium being much more plentiful in nature than those of potassium, and the most abundant of all being sodium chloride, it was natural that the latter should be seen as a possible source of soda for the soap industry; and the French chemist Nicholas Leblanc (1742–1806) in 1791 succeeded in developing a workable process for converting common salt into soda. In the earliest Leblanc process the first stage was the treatment of common salt with sulphuric acid to form sodium sulphate (saltcake) with the liberation into the atmosphere of hydrochloric acid gas, and the second stage the heating of the saltcake with coal or coke and limestone or chalk to produce crude sodium carbonate (ball soda) in solution and calcium sulphide and coal ash as waste products. Waste heat from the furnaces was used to evaporate the soda solution, producing 'soda ash' or anhydrous sodium carbonate. The stages may be represented simply thus:

- 1 Sodium chloride + Sulphuric acid = Sodium bisulphate +  
 $\text{NaCl}$                      $\text{H}_2\text{SO}_4$                      $\text{NaHSO}_4$   
 Hydrochloric acid  
 $\text{HCl}$
- 2 Sodium chloride + Sodium bisulphate = Sodium sulphate +  
 $\text{NaCl}$                      $\text{NaHSO}_4$                      $\text{Na}_2\text{SO}_4$   
 Hydrochloric acid  
 $\text{HCl}$

The first reaction begins at ordinary temperatures, but requires heat. The end product, 'saltcake' is melted with limestone or chalk and coal or coke:

- 3 Sodium sulphate + Carbon = Sodium sulphide + Carbon dioxide  
 $\text{Na}_2\text{SO}_4$                      $2\text{C}$                      $\text{Na}_2\text{S}$                      $2\text{CO}_2$
- 4 Sodium sulphide + Calcium carbonate = Sodium carbonate +  
 $\text{Na}_2\text{S}$                      $\text{CaCO}_3$                      $\text{Na}_2\text{CO}_3$   
 Calcium sulphide  
 $\text{CaS}$

From these later reactions some carbon monoxide is produced and of course coal ash.

The first works in England to operate the Leblanc process was at Walker, east of Newcastle-upon-Tyne, using salt from a brine spring struck in the Walker Colliery. Various previous soda-making processes had been tried at this works but in 1823 it had become solely a Leblanc soda factory. In the same year the second works in the country was established, by James Muspratt (1821-71) in Liverpool. On both Merseyside and Tyneside the industries thrived, and both areas became important for soap making. As Leblanc soda making grew, however, there was a rising tide of protest in Widnes, St Helens, Jarrow, South Shields and other places against the pollution resulting from the release of hydrochloric acid gas into the atmosphere. As much as 12½ cwt of gas was produced from every ton of salt, and this flowed from the chimneys of the chemical works to defoliate the trees and poison livestock. The result of this agitation was the passing of the Alkali Works Act in 1863, which stipulated that at least 95 per cent of the hydrochloric acid gas had to be condensed. An alkali inspectorate was also set up to see that the law was obeyed. (This early involvement in clean air

activity laid the foundation of the practical approach to problems that still exist in the UK, where enforcement of the 'best practical means' of abatement is preferred to the setting of arbitrary emission levels.) The enormous chimneys used by the soda factories to dissipate the gases—one at St Rollox, Glasgow, was 420ft high—had to be replaced by condensers most usually in the form of towers in which the gas passed upwards through beds of coke while water flowed down through them. The alkali manufacturers now had a new by-product, hydrochloric acid, with which to pollute rivers and streams instead of the atmosphere. Before long, however, all but the smallest works were using it for making bleach.

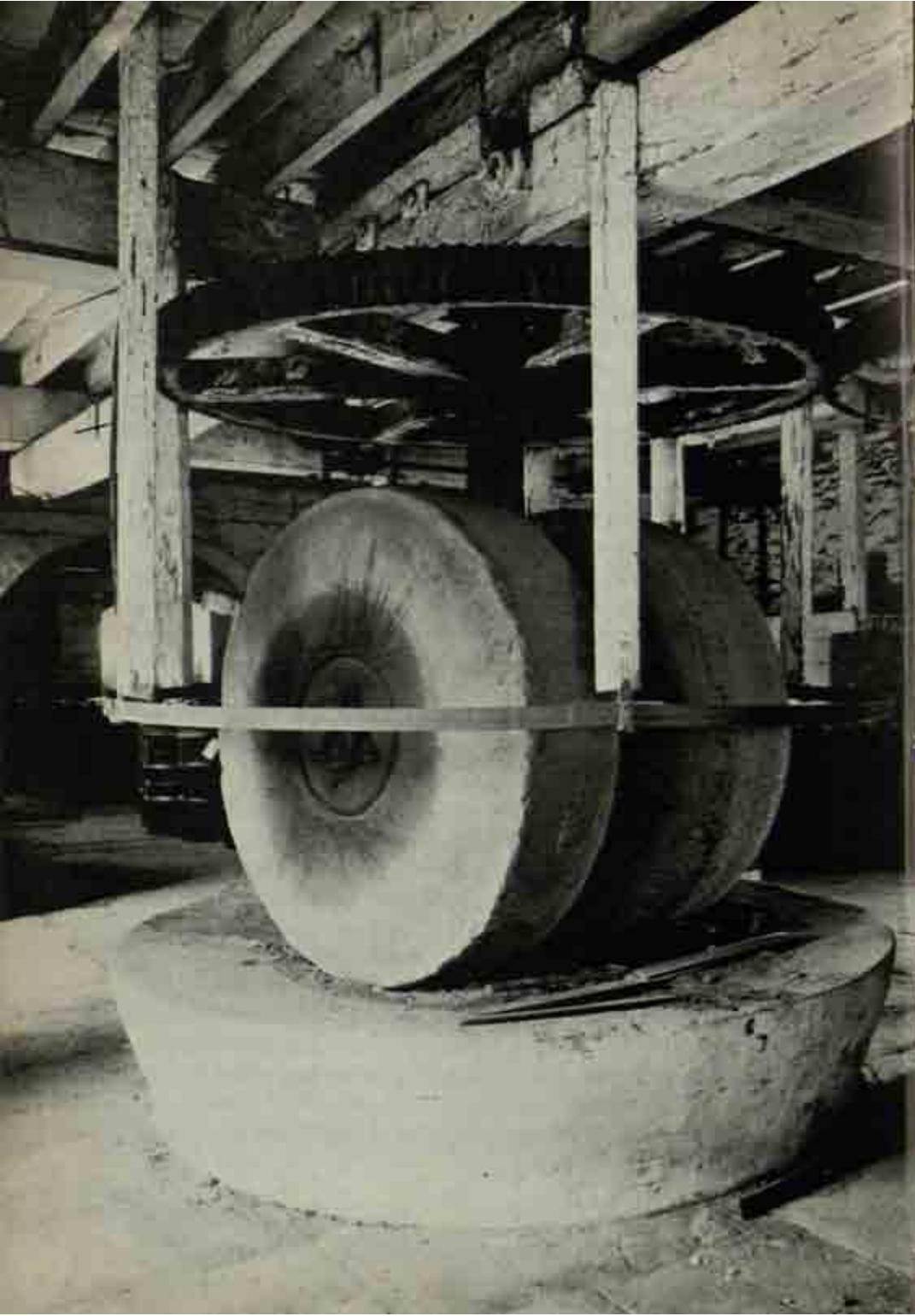
The soap industry of Merseyside, which developed in Widnes, Warrington and Liverpool, produced a wide range of products and eventually gave birth to a completely new industrial complex that was to become the home of one of the world's great soap combines. William Hesketh Lever (1851-1925) founded Port Sunlight (100/SJ 3484) on the Wirral or Cheshire side of the Mersey estuary in 1888, and developed there a factory and model village for his workpeople far in advance of anything previously built. Viscount Leverhulme, as he eventually became, was not a romantic idealist but a social realist as well as a successful businessman. He talked of the days when 'Workpeople will be able to live and be comfortable in semi-detached houses, with gardens back and front, in which they will be able to know more about the science of life than they can do in a back slum.' Port Sunlight was the realisation of this philosophy, the creation of an ideal community. Groups of 'Tudor' cottages with plenty of traditional half-timbering and moulded plasterwork were arranged in carefully contrived arcs around little greens and enclosed spaces at an average density of only eight dwellings per acre. In a way Port Sunlight did a disservice to the movement towards better workers' housing, for although it was important environmentally, it was not conceived with any thought of financial realism. The much more mundane Cadbury experiment at Bournville, near Birmingham (131/SP 0481), based on a return of 4 per cent on the investment in building in order to encourage local authorities to imitate it, had a greater influence on subsequent developments. The industrial archaeologist as a student of industrial landscapes should visit both. At Port Sunlight, in the Lady Lever Art Gallery, he will also find a fine portrait in oils of Thomas Telford.

## BLEACHING AND DYEING

The demand for a chemical bleaching agent that was rapid in action was largely created by the cotton fabric side of the textile industry, which had grown beyond the stage where the natural action of sun, rain and wind on cloth spread out in bleachfields could cope with the enormous output. It was the bleaching action of chlorine, first recognised in 1785 by the French chemist C. L. Berthollet (1748-1822), which was eventually applied to fabrics. The manufacture of a chlorine-based bleach was first developed on a large scale by Charles Tennant (1768-1838), for which he set up the St Rollox chemical works in Glasgow in 1799. Previously sulphuric acid had been used to liberate chlorine from a mixture of common salt and manganese dioxide, but Tennant patented a solid compound of chlorine and lime known as chloride of lime or bleaching powder, which was less harmful to the people who made and used it than chlorine in aqueous solution. In 1800 Tennant was selling his bleaching powder at £140 per ton from his Glasgow factory. As the industry grew and techniques improved, the price dropped until in 1870 it had fallen to £8 10s per ton, presenting an enormous saving to cloth manufacturers. In the 1860s techniques for recovering chlorine from the waste hydrochloric acid of Leblanc soda plants were developed, and this eventually became not only the main means of producing bleach but in many cases the primary source of income for the Leblanc works.

Cleaned and bleached cloth often had to be dyed, but although the soap and bleach industries were revolutionised in the early nineteenth century, development of 'fast' dyes came much later. The principal dyes used throughout Europe were much the same as they had been for centuries and included vegetable-based materials such as saffron, turmeric, woad and logwood. A mill engaged in the logwood dye industry remained in use until 1964, and can still be seen at Keynsham in Somerset (156/ST 656679). Albert Mill, Keynsham (Plate 58), contains a logwood chipper and a set of stone edge-runners for crushing the wood chips, both powered by an external iron waterwheel of 18ft 6in diameter and 9ft width. The woods included fustics from Jamaica, South America, Greece and Turkey for yellow dyes; Brazilwood for pinks and reds; ebony to give olive green for glove leathers; and New Zealand Tanekaha to supply a golden brown colour.

In order to make the dye adhere to the fabric, mordants had to be used,



and some of them significantly altered the character and colour of the dyes themselves. One of the earliest was copperas, which itself was used for ink and black dye. Copperas was obtained from the oxidation and hydrolysis of iron pyrites ( $\text{FeS}_2$ ), sometimes called 'fool's gold'. The process, carried out in large open pits initially at Queenborough on the Isle of Sheppey and at Deptford, took up to 5 years, the copperas liquors ( $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ ) being led away to cisterns as the slow atmospheric oxidation took place. In the eighteenth century numerous works taking advantage of the pyrites found in locally mined coal grew up on Tyneside. Besides its use as a dye and mordant, copperas was also a source of 'oil of vitriol' or concentrated sulphuric acid, which resulted in a highly profitable by-product in the form of Venetian red, an iron oxide.

More important as a mordant was alum, a double sulphate of potassium and aluminium, which was produced first in England at Guisborough in Yorkshire in 1595. Alum shales outcrop extensively on the North Yorkshire coast and inland on the northern and eastern slopes of the Cleveland Hills. Huge quarries, as at Ravenscar (93/NZ 9701) and on the cliffs at Boulby (86/NZ 7519) and Kettlewell (86/NZ 8415), were excavated during the nineteenth century to obtain the shales, which were subsequently calcined, usually in heaps on the floor of the quarry itself. The calcined shale was then put into stone leaching or lixiviation pits usually floored with large stone flags and the resulting liquor was evaporated in lead or iron pans over coal fires. Extensive remains of the alum extraction process have been excavated recently by the Teesside Industrial Archaeology Group on the edge of Boulby cliffs in North Yorkshire. Sandsend (86/NZ 862128), north of Whitby, has the scanty remains of a small wharf built for shipping out alum.

During the second half of the nineteenth century the dye industry changed rapidly as the result of work begun by W. H. Perkin (1838-1907) in 1856 while studying under A. W. von Hoffman (1818-92). Hoffman came to London from Giessen in Germany as the first superintendent of the Royal College of Chemistry, established in 1845. Hoffman and Perkin carried out pioneer work on coal-tar derivatives, and it was one of these, the first commercially successful synthetic dye, a mauve, that Perkin offered to

Pullar's of Perth in 1856. The subsequent history of the synthetic dye industry during the latter part of the nineteenth century provides an example of a technological takeover even more startling in its proportions than the American rise to pre-eminence in machine tool design in the same period.

Germany had led the world in pure organic chemistry for more than 20 years before Perkin's original discovery, Hoffman being one of her leaders. By the 1870s Germany had overtaken British output of aniline dyes. Between 1886 and 1900 the six largest German firms took out 948 British patents, whereas the six largest British firms took out only eighty-six. By 1900 Germany had 90 per cent of the world market. The prominence of the chemist in the German dye industry also provides a salutary indication of the appreciation of the need for high level research. In 1900 the six largest German firms employed some 18,000 workpeople, 1,360 commercial staff, 350 engineers and technologists and 500 chemists. At the same date there were less than forty chemists, of generally lower quality, employed in the whole British dyestuffs industry. By the interwar years German chemical pre-eminence had widened into pharmaceuticals, synthetic perfumes and flavouring, saccharine, synthetic rubber and numerous other products. After A. W. von Hoffman left London in 1865 to take up the Chair at Berlin, there was no chair of organic chemistry in Britain until 1874! Study of the Industrial Revolution is often preoccupied with technological innovation, growth and capture of world markets, especially when seen from the standpoint of Britain. The machine tool and chemical industries provide examples of how an advanced country with well established traditional techniques can fall back into a state of relative underdevelopment. The fact that Britain and the United States were forced into a position of having to catch up emphasised the importance of scientific and technical education and underlined the fact that the educational system necessary to provide scientists and science-based engineers needs to be set up a generation in advance.

#### SULPHURIC ACID

Sulphuric acid was one of the most important base chemicals of the 'chemical revolution' of the nineteenth century, being required in ever-increasing quantities. Indeed, its rate of consumption may be regarded as one of the measures of the commercial and industrial prosperity of a nation, so widely

is it used. Both the Leblanc soda process and Tennant's bleach making depended on it, as did numerous subsequent developments. Knowledge of the acid dated back many centuries and descriptions of its distillation from green vitriol or ferrous sulphate ( $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ ), itself derived from copperas, occur as early as 1570. Continuous manufacture in Britain probably began in Twickenham and Richmond in the 1730s and 1740s. A major advance came in 1746 when John Roebuck (1718-94) and Samuel Garbett (1717-1805) set up a sulphuric acid plant in Birmingham, probably to satisfy the increasing demand from local metal industries for the acid as a cleaner and stripper. In this and subsequent processes lead chambers were used (sulphuric acid does not attack lead) in which nitre or saltpetre (potassium nitrate,  $\text{KNO}_3$ ) and pure sulphur were burned over a shallow depth of water on to which the fumes condensed. The process was repeated at intervals until the liquid had reached the required strength.

The availability of cheap sulphuric acid by the lead chamber process was one of the great inventions of the Industrial Revolution, making available soda instead of the more expensive potash for the soap and glass industries, freeing greater supplies of potassium salts for agriculture and, after 1845, being used directly in the manufacture of phosphatic fertilisers (superphosphates), which became the principal outlet for sulphuric acid. In addition it was used for the manufacture of bleach and explosives. After 1830, when Chilean saltpetre (sodium nitrate,  $\text{NaNO}_3$ ) replaced the potassium salt, sulphuric acid became cheaper still. By the 1870s the lead chamber process had reached a state of great efficiency, with its main concentrations in the North East of England, Glasgow, Lancashire and London. Today the lead-chamber process is completely obsolete and remains of it are virtually non-existent, the high value of scrap lead encouraging rapid demolition. A direct contact process, eliminating the use of saltpetre, was propounded in the 1830s but not taken up commercially until 1914. A major producing area is now Teesside, using local supplies of anhydrite (calcium sulphate,  $\text{CaSO}_4$ ), mined at Billingham.

#### GUNPOWDER

Gunpowder manufacture is not truly a chemical industry process, as it involves the mixing of sulphur, saltpetre (potassium nitrate) and charcoal

(carbon) without any reaction occurring between them. Of Chinese invention, its first European use—probably as the result of re-invention—was in Germany in the mid-thirteenth century and it quickly spread from there. Its use for blasting purposes in England probably dates from the 1620s, and in Cornish mines from 1689. More sophisticated and controllable explosives, including dynamite and gelignite, replaced it during the nineteenth century. The industry developed in several areas of Britain and a number of sites still contain recognisable and comprehensible remains. In the Lake District at Blackbeck (89/SD 334859), near Bouth, lies the site of a mill operating from 1862 until 1928, which is now a caravan park. The approach lane was once a railway track from the Leven estuary. The office and weigh-house still survive at the site's entrance, and there are also some steam pipes from the original engine-house, water power not being used here. The Lowwood works of 1799 stood near Haverthwaite beside the River Leven (89/SD 347837), but is now substantially overgrown. More extensive remains can be seen, however, at Elterwater (89/NY 328048), with two waterwheel pits, now occupied by turbines, a number of the original buildings, edge-runners and a small howitzer used for testing powders in the grounds of Elterwater Hall. The industry started in the Lake District in 1764, using saltpetre imported from India and later Chile and Germany, sulphur from Italy and Sicily and charcoal from local birch and alder trees, although juniper was used at Lowwood. The last mill closed in 1937.

There is another important gunpowder site, currently the centre of a major conservation programme, at Faversham in Kent (172/TR 009613), where the Chart Mills are being restored. For some 300 years before the closure of the works in 1934 Faversham was a major centre of the gunpowder industry. Much of the buildings and machinery was destroyed but in the Home Works, oldest of all and once the Royal Gunpowder Factory, some of the plant survived. Known as Chart Mills, they contain two pairs of gunpowder mills consisting of edge-runners, each pair worked in tandem off a single large waterwheel. After some 30 years of neglect, restoration by the Faversham Society is now well in hand. Another area of gunpowder manufacture was Devon, where there were three factories working in 1890. Remains of one of these can be seen on Dartmoor, where the buildings have been incorporated into Powder Mills Farm (175/ST 628769), which stands north of the B3212 Princetown to Moretonhampstead road. The



59 Gun barrel proof house, Birmingham, built in 1813

walls of three wheelhouses and two tall chimneys can be seen on the moor behind the farm, while a small mortar once used for testing the powder stands by the farm entrance. Storage of gunpowder presented very special problems of security, and powder houses, usually small, substantially built brick or stone buildings, are a common feature of many mining and quarrying areas. The dangers arising from powder on board ships while they were in port was solved at Bristol by the construction of a powder house on the River Avon (156/ST 537765) at which ships could discharge any gunpowder before entering the crowded quays and wharves of the city.

#### PAPER

As with gunpowder, the manufacture of paper hardly qualifies for inclusion among the chemical industries, although since the 1870s at least the pulp from which it is produced has been boiled with various acid and alkaline reagents to purify it. Up to the beginning of the nineteenth century all paper products were made by hand, using a vat and hand mould. The raw material from which the paper pulp was derived was essentially rag, but

during the latter half of the nineteenth century this was progressively replaced by cellulose fibre from coniferous trees. A variety of additives were mixed with the pulp to improve the quality of the finished paper, and of these, china clay, used to make high-quality dense white papers, is the most important. In the original hand processes a fibrous suspension, highly diluted in water, is contained in the vat. The vat man dips the hand mould, a fine wire screen surrounded by a wooden frame (the deckle), into the vat and lifts out some pulp from which the water is allowed to drain. The deckle is then removed and the mould with the fibrous web of pulp lying on it is passed to the couch man. He transfers the web on to a woollen felt. Further webs on felts are stacked on it and the whole transferred to a screw press where excess water is removed by pressing. Finally the webs are removed from the felts and hung in a loft for drying in the atmosphere.

The limitations of this batch type of process are obvious, and the demand for paper, which had been increasing with the spread of printing, was eventually satisfied by the Fourdrinier machine and cylinder mould. Henry Fourdrinier (1766-1854) developed a machine in the early years of the nineteenth century in which the pulp was fed continuously on to a moving belt of gauze through which water was allowed to drain. Successive squeezing eliminated further water from the web until it was strong enough to support itself, when it passed to a series of steam-heated rolls that eliminated the remaining undesirable moisture. A modern papermaking machine is usually of this basic Fourdrinier type, often several hundred feet long. The proportion of the machine involved in removing water from the web either by drainage or steam represents over 90 per cent of this total length. The speed at which paper, and more particularly multi-layer boards, can be produced is determined by the rate at which the water can be removed from the webs. A development in this field during the early 1960s was the 'Inverform' machine in which water was removed by gravity from below and by vacuum box from above the webs. The prototype of this machine is preserved in Bristol City Museum. A national papermaking collection developed by the industry at St Mary Cray in Kent has now been transferred to the North Western Museum of Science and Technology in Manchester.

The distribution of eighteenth- and nineteenth-century paper mills in the period before the industry became focused on a relatively small number of large production units was based on three primary locational factors. A

source of rags was a major requirement, so the proximity of a large urban centre was essential, and this centre also provided a market for the finished paper. The third requirement was large quantities of clear water. In the Bristol area alone the Bristol Industrial Archaeological Society has identified thirty-eight sites of extinct paper mills in addition to the seven where production still continues. Most of these were located on streams such as the Chew and Axe, flowing from the Mendips. At Bathford (156/ST 790671) a small mill specialises in the production of 'India' papers for bibles and dictionaries, made on a single 84in machine. A 1912 horizontal-tandem compound mill engine by Wood Brothers of Sowerby Bridge drove the machinery until 1966, when the mill was converted to electric power. The engine remains *in situ*. Wookey Hole Mill, near Wells (165/ST 531466), owned by W. S. Hodgkinson & Co Ltd, is probably the largest hand-made paper mill in the world, dating back to 1610 or even earlier. It produces mould-made account books, deckle edge notepaper and paper for bank-notes. Of the abandoned mills in the area, numerous buildings survive, some converted to other purposes, but little equipment remains. At Slaughterford (156/ST 839738) a rag mill used for preparing the raw materials is now derelict but the iron waterwheel still survives.

#### RUBBER

The origins of the modern rubber industry are twofold, based on two quite distinct vegetable raw materials. One of these was gutta-percha, a tree gum from Malaya introduced in the 1840s for insulating purposes; it gained some importance in the manufacture of submarine telegraph cables and the first cables laid under the streets of London. Eventually the superior qualities of rubber made the harder and more brittle gutta-percha obsolete, but not before the irrepressible Victorian enthusiasm for anything new had resulted in household ornaments and even tableware being made of it. Several companies were formed, mainly in London, to process the gum, and the name of one of these, the S. W. Silver & Co Gutta Percha and Rubber Works, founded in 1852, is perpetuated in Silvertown (161/TQ 410800), between the Royal Victoria Dock and Woolwich Reach.

Rubber is made from the latex of a tree native to South America, its great attraction to European industrialists of the late eighteenth and early

nineteenth centuries being its unique qualities of elasticity and impermeability. A patent was granted as early as 1820 to Thomas Hancock (1786-1865) for making rubber latex springs, and in 1823 Charles Macintosh (1766-1843), a Glasgow chemical manufacturer, patented a technique for dissolving rubber in coal-tar naphtha, a by-product of the gas industry, and applying the solution to fabric. He set up a works in Manchester for making waterproof garments—the misspelt mackintosh. The problems of stickiness and perishability to which these early rubbers were prone was solved by the introduction of the 'vulcanisation' process, in which sulphur was mixed with the rubber. Developed in 1841 by Charles Goodyear (1800-66) in the United States, the process was offered to Macintosh in England, but Macintosh's partner Thomas Hancock worked out for himself how to vulcanise rubber and filed a British patent in 1844, beating Goodyear by days. Vulcanising resulted in a much more stable material and provided the foundation on which the rubber industry could expand, initially with products like rubberised fabrics and shoe soles and later on a bigger scale altogether as the result of the growth of the motor industry and the establishment of huge factories like Fort Dunlop on the outskirts of Birmingham.

Much of the equipment used in the mixing of the constituents of rubber, which in the case of tyres includes powdered carbon, was until recently surprisingly primitive. Masticators, rather like enormous mangles, are used and an early example, from an Avon factory in Wiltshire, is preserved in Bristol Museum. Calendering, introduced in 1836 and another basic manufacturing process, consists of rolling rubber into the surface of fabric under great pressure between a series of horizontal rollers arranged one above another. A variety of criteria have affected the distribution of the rubber industry in Britain but an unusual locational factor was responsible for the establishment of the industry in the Bradford on Avon and Melksham area of north-west Wiltshire—the availability of empty wool textile mills. The industry still occupies some of these, although its modern expansion has been based on new buildings on new and larger sites.

#### OIL

During the twentieth century the chemical industry has had a new raw material in oil, which has provided the basis for a vast range of products,

including detergents, organic solvents, epoxy resins, sulphur, sulphuric acid and numerous plastics. Most of this industry is based on imported oil, but a few native sources are actively worked. In east Nottinghamshire around Eakring (112/SK 6762) and in north Leicestershire around Plungar (122/SK 7734) unmanned pumps may be seen lifting oil from wells. They are in effect beam engines—an electric motor driving one end, the other connected to the pump rods—and their characteristic movement has gained them the name 'nodding donkeys'.

The other main source, now no longer worked, was oil shale, of which the largest concentration in Britain occurs in the Lothians of Scotland. Exploitation began in 1851 when James Young (1811-83) a brilliant scientist who had assisted Faraday and later managed Tennant's chemical factory in Manchester, started mining the shale, from which he refined paraffin and paraffin wax. The industry grew slowly until 1864 when Young's patent lapsed, and by 1870 ninety-seven firms had been founded of which nearly a third had already failed. American competition after 1900 precipitated a decline and the industry finally became extinct in 1963. Remains are numerous, the most obvious being the waste tips known as 'bings'. At Torbane, near Bathgate, West Lothian (61/NS 953668), stands the bing from Young's pioneer enterprise of 1851; this incidentally is where the geological name Torbanite, applied to the oil shales, originated. At Broxburn (61/NT 087728) in 1862 the discovery of large shale deposits resulted in a boost to the Scottish oil industry. This village and nearby Winchburgh to the north are products of the industry, which has left a spectacular landscape of bings to the east of the B8020 road running between the two. The refinery, founded in 1883, was south of Broxburn at Pumpherston. In north Somerset oil shales were worked early this century on the sea cliffs east of Watchet at Kilve (164/ST 147439), where the remains of a distillation plant in the form of a brick tower still survive.

Perhaps the most spectacular source of oil in Britain, and one of the earliest to be commercially worked, can be seen in the so-called Tar Tunnel at Coalport, Shropshire (119/SJ 694025). Excavated in 1787, probably to give access to coal, the tunnel struck considerable quantities of natural bitumen, which were exploited well into the nineteenth century. Today the tunnel is administered by the Ironbridge Gorge Museum Trust and is accessible to visitors, who may view the cavernous 'tar' wells leading off

the brick-lined tunnel at intervals along its length.

The sector of the chemical industry using oil for its raw material is perhaps too modern a development to form a legitimate area of study for the industrial archaeologist. As has been pointed out elsewhere, however, it is not absolute date that provides a criterion by which the industrial archaeologist can work, and in industries where the rate of change is rapid much of undoubted historical and archaeological significance will be lost if it is not recorded. Again the point about the complexity of the process must be made, as this places additional responsibility on industries themselves to ensure that there is a rational and comprehensive approach to the preservation of archival material and the maintenance of a record of evolution. To the industrial archaeologist engaged in the examination of the physical remains of the chemical industries this chapter can only provide the most generalised of indications on the directions in which to look. Certainly the obvious remnants of the industry vastly understate its importance in the industrial development of Britain and even if the opportunities for conservation of significant plant and buildings are limited, and probably in many cases difficult to justify, the need for the retention and study of documentary material is paramount.

## 12 Public Utilities

THE continuing and rapid processes of industrialisation throughout the nineteenth century had profound effects upon the way of life of the population. Industrialisation brought with it large-scale urbanisation, destroying the old balance between town and country and creating within the newly bulging towns horrifying conditions of overcrowding, squalor and disease. Liverpool's population increased from 82,000 in 1807 to 202,000 in 1831, and this before the massive immigration from Ireland after 1845. Leeds, at the centre of the West Riding woollen industry, climbed from 53,000 to 123,000 in the same period. In Birmingham, Glasgow, Manchester and Sheffield the pattern was the same, while London continued to maintain its superiority in size over all other towns.

The techniques of town living had become well established before this explosive growth in the early nineteenth century, but the sudden increase in scale, coupled with overcrowding, completely swamped the simple processes of water supply from wells, and of sewage disposal through open gutters (or, in the more enlightened towns, by 'rakers' or night-soil men). The water closet, patented by Joseph Bramah in 1778, could be little used because there were few proper sewers and often no regular water supply. Enormous pressures were put upon towns and their administrative systems, such as they were, but cholera epidemics, a prevailing *laissez faire* attitude to corporate initiative, a lack of adequate medical information and the total absence of any 'public service' technology all militated against reform and improvement. But reform did come, and a combination of private companies and, increasingly, local authorities, gradually brought about the provision of water, gas and drains, transport, housing and other urban necessities. From the mid-1830s towns had powers to supply water, by the 1840s to provide gas and in the 1870s and 1880s to build tramways and supply electric light. The Public Health Act of 1875 was only one of a large number of legislative moves to ensure proper sanitation and maintenance of good general living conditions.

With these developments came a new breed of professionals. The British Association of Gas Engineers, formed in 1863 under the famous sanitary

engineer Thomas Hawksley (1807-93), was followed 10 years later by the Institution of Municipal Engineers. By the end of the century three more professional groups had been formed to cover sanitary engineering (1895), water supply (1896) and heating and ventilation (1897). Great works, privately and publicly financed, sprang up in and around the expanding urban areas and today provide some of the most tangible physical evidence of the improvement in the quality of town life during the second half of the nineteenth century.

#### WATER SUPPLY

A prime necessity of life and of many industries is water, and the need for larger and better supplies, of which those concerned with public health were the first to be aware, became generally recognised by the early nineteenth century. The major sources of supply are rivers and lakes, reservoirs constructed specially to store water and pervious water-bearing rocks underground. Pumping stations for lifting water from deep wells are most numerous in the Midlands and south-eastern England, although they also occur in other places where water is taken from rivers. Large dams and reservoirs are generally confined to mountainous country in Wales, Scotland and the Pennines and often provide water for cities such as Birmingham, Liverpool and Glasgow by long-distance aqueducts.

Some of the first large-scale water installations in Britain were built to serve London in the early years of the seventeenth century. Under the direction of one man, Hugh Myddelton (?1560-1631), and largely at his personal expense, the New River, some 40 miles long was built to bring spring water from Hertfordshire into the City. The New River Company was the first of London's great water supply companies and the aqueduct, much of which is still in use today, was formally opened on Michaelmas Day, 1613, when water was let into the Round Pond at Clerkenwell. Traces of the pond, together with remains of Smeaton's engine-house of c1768, may be seen at the Metropolitan Water Board headquarters at New River Head, Rosebery Avenue, Islington (160/TQ 313828). Of the conduit carrying the New River itself, a good section remains between Bullsmoor Lane, Waltham Cross and Greens Lane, N4 (160/TQ 318878). A nineteenth-century straightening, by which the New River is carried in a siphon pipe across the Cuffley Brook, may be seen near Maidens Bridge, Forty Hill,

Enfield (160/TQ 343987). The old course is still traceable winding round Forty Hill. A further shortening, dating from 1859, runs between Myddleton Road (160/TQ 306916) and Hornsey High Street.

The New River Company, which took over the famous London Bridge Water Works, was soon to be followed by others, and by 1822 nine separate companies were serving the metropolis. This was reduced to eight in 1845, when the Southwark & Vauxhall company was formed by the amalgamation of two of them, and in 1902, after continued pressure from the London County Council, a single authority, the Metropolitan Water Board, was formed to take over them all.

The numerous companies set up in the early nineteenth century rarely had the capital to develop major sources of supply, especially where reservoirs or long aqueducts were required. Provision was generally intermittent, often with the water turned on for only an hour or two each day. This was very unsatisfactory where water was needed for street cleansing, fire-fighting, sewer-flushing and for public baths and wash-houses, the first of which had been opened in Liverpool in 1842. For these reasons most of the larger towns took over their private water companies, frequently following this with massive capital expenditure on reservoir or pumping schemes. Relatively few of the companies were large and efficient enough to resist these takeovers, although those serving Bristol, Portsmouth, south Staffordshire, and Sunderland and South Shields retained their independence.

In the early nineteenth century a number of Acts were passed authorising water undertakings to take water from rivers or to construct reservoirs without any restriction as to the rate of abstraction, but generally speaking the rights of riparian owners using water to power mills and factories were protected by defining minimum amounts of compensation water. Dams were at first constructed of earth, a watertight core of puddled clay being faced on both sides by filling material; on the water side stone pitching covered the face to prevent erosion, while the outer face was covered in soil and then grassed. To prevent water from passing under the dam, the clay core was set in a trench dug down to a watertight foundation such as rock or shale. The early earth dams were mainly in the Pennines, built to serve cities like Sheffield and Manchester. The first large masonry dam, on the River Vyrnwy in Montgomeryshire (117/SJ 018193) dates from 1881-92 and was built to serve Liverpool. It is 161ft high and 1,172ft long. Behind it on the

lake side stands a remarkable turreted 'castle' containing the valve controls.

From the industrial archaeological point of view the most spectacular installations associated with water supply are the steam pumping engines built to lift water from wells or to pump it to high-level storage reservoirs. Engines were generally of the beam type, superbly finished and maintained, set in ornate and frequently quite exotic buildings, and surrounded by pools, trees and immaculately manicured formal gardens. Two such engines are preserved by the Bristol Waterworks Company at Blagdon in Somerset (165/ST 503600), and at Papplewick in Nottinghamshire (112/SK 582522) two riotously ornamental rotative beam engines (see Plate 12) by James Watt & Co have come into the care of a preservation trust. Papplewick pumping station was erected in 1883-5 to pump water out of the Bunter sandstone for the growing needs of Nottingham, and represents the ultimate in elaborate construction and setting. In Sunderland Ryhope pumping station (78/NZ 404525) is also being preserved, and in part of the adjacent boiler house a museum of water supply equipment is being established, again by a private preservation trust, in this case working in close liaison with Sunderland Museum. The four Cornish pumping engines at Kew Bridge waterworks, Brentford (170/TQ 188780), last worked in 1944; they are undoubtedly the finest single concentration of the breed in the world and are preserved by the Metropolitan Water Board, from whom permission to view can be obtained.

In the late nineteenth century and early twentieth vertical triple-expansion steam engines, similar in general layout to those used in ships, supplanted the beam type. A number are still in use, including two 1,008 hp Worthington Simpson engines (see Plate 15) installed at Kempton Park Waterworks in 1928 and believed to be the largest land-based triples in Britain. The same works has five further triples built by the Lilleshall Company of Shropshire in 1900 but now out of use. At the opposite end of the scale a single triple, also by Lilleshall, can be seen by appointment at the Chelvey, Somerset, pumping station (165/ST 474679).

Reciprocating plunger or piston pumps were usual with most water pumping engines but towards the end of the nineteenth century centrifugal pumps, notably those made by Gwynne, were used increasingly. An extraordinary water pumping station, although now devoid of its original equipment, forms a noteworthy feature of Marshall Place, Perth (55/NO 121232).

Designed in 1830 by Dr Adam Anderson, then rector of Perth Academy and later Professor of Natural Philosophy at St Andrews, it has a central rotunda with drum and dome flanked by rectangular north and south wings and an annexe to the west. The drum and dome forming the reservoir are of cast iron decorated with Ionic pilasters and supplied by the Dundee Foundry Company. This remarkable essay in the assimilation of classical forms to functional needs is not only ingenious but a surprisingly satisfactory piece of design. Numerous other humbler water towers can be found all over Britain, often in commanding positions and visible for many miles because of their need to be higher than the area they are supplying. Low-lying south Lancashire has a number of good examples, notably Victoria Tower on Greetby Hill, near Ormskirk (100/SD 423087), and a neighbour east of Tower Hill (100/SD 423085) to the south. There is a fine concrete water tower at Newton-le-Willows near the M6 Motorway (100/SJ 599957), and a commanding brick and stone tower at Frith Heath, Godalming (170/SU 970445), in Surrey.

#### WASTE DISPOSAL

Disposal of town waste had become a major problem by the middle of the eighteenth century, and although London had since the 1660s, in theory at least, some sort of rubbish disposal organisation, most other cities had nothing at all. Rivers, streams or tidal estuaries and the sea provided the means of carrying away the unwanted detritus of urban humanity, and in some parts of Britain this situation still applies. The Thames was London's *cloaca maxima*, which was supposed to take away on each tide the city's waste products. The realisation that diseases such as cholera and typhoid were water-borne, and that all too often drinking water and waste water came into contact with each other, provided the great incentive to install sewers and sewage treatment plants. In two cholera epidemics in London in the middle of the nineteenth century nearly 20,000 people died, emphasising particularly the need for systematic methods not only of water supply and distribution but, more important, the disposal of waste water in underground pipes to areas away from the town, where it could be suitably treated.

In 1855 the Metropolitan Board of Works was created, with Sir Joseph Bazalgette (1819-91) as its engineer, to provide a system of sewers to prevent 'all or any part of the sewage within the Metropolis from flowing into the

Thames in or near the Metropolis'. Bazalgette's monumental undertaking provided the framework on which most of London's sewage disposal system still depends, and although much of it is below ground and not easily available for the industrial archaeologist to examine, some of the surviving surface remains exhibit a magnificence of conception and execution equal to the works of many a better known engineer. One of the main difficulties to be overcome in providing London with an efficient sewerage system was to carry the waste products away from the urban area itself, as most of the existing sewers flowed at right-angles to the Thames. Bazalgette's solution was to construct major sewers parallel with the river on each side of it—the Northern and Southern Outfalls—running to Barking in Essex and Crossness in Kent. Generally the gradient was sufficient for a gravity flow, but at intervals a pumping station was needed to achieve enough height to maintain an effective gradient. An example is at Greenwich High Road, Deptford (161/TQ 377772), where four beam pumping engines lifted low-level flow 18ft into the Southern Outfall. Only the Italianate pump house of 1864 now remains.

The often extravagant lengths to which the water supply companies went with their pumping stations were exceeded only by the works built by those authorities responsible for the eventual disposal of the waste. The Metropolitan Board of Works perpetrated two such works which, in all their elaborate mid-Victorian improbability, are quite without parallel. One, the Abbey Mills sewage pumping station in West Ham (161/TQ 388832), was built between 1865 and 1868 and originally housed eight beam engines, which were removed in the 1930s. The Venetian-Gothic style building with its exotic interior cast-iron work survives, however, a remarkable monument to the beginnings of the anti-pollution movement. Even more unlikely is the Southern Outfall pumping station in Thamesmead. Here the Crossness sewage treatment works (161/TQ 484811), also built in the mid-1860s, is still complete, with four 125hp beam engines by James Watt & Company. Now out of use and iced all over by hordes of invading pigeons, the incredible cast-iron tracery of the central octagonal framework supporting the beam floor has taken on the appearance of a fantastic petrified cathedral. While efforts are being made to preserve Crossness pumping station, three other sewage pumping installations, already safe in the hands of local authorities, are accessible to visitors. In Shrewsbury the Coleham (118/SJ 496121) beam

pumping engines are preserved and run from time to time on electric power; built in 1900 by W. R. Renshaw of Stoke-on-Trent they were in use until 1970 and then taken over by Shrewsbury Museums. In Leicester, Abbey Lane pumping station (121/SK 589066), again with beam pumps (built by Gimson in the exotic manner), is being preserved as the focal point of a Museum of Technology for the East Midlands. Eastney sewage pumping station (181/SZ 675989) is one of a number that clear sewage and surface water from low-lying Portsea Island, on which Portsmouth stands. Originally two Clayton beam engines, installed in 1868, provided the power, but they were scrapped and replaced by two large compound engines by James Watt & Co, installed in 1886-7. These in turn became redundant in 1954, when four English Electric/Sulzer electric pumps took over the main load. The Watt engines and their engine-house have recently been restored by Portsmouth Museums and opened to the public as the nucleus of an industrial museum. Also on the site are three T2 type 170bhp Crossley double-ended (opposed-cylinder) gas engines driving Tangye centrifugal pumps. Dating from 1904, these engines are still maintained for standby use and may eventually be preserved.

As an example, Portsmouth illustrates very graphically the improvement in living conditions and reduction in mortality that resulted from better public health, largely brought about by good drains and sewers. The Sewage and Drainage of Towns Act of 1845 marked the beginning of steady progress in a town which had a particularly acute drainage problem, especially on Portsea Island, where the highest and most densely populated area was only 12ft above the level of ordinary tides. Two large pumping stations were built to pump effluent from the sewers, at Eastney in the 1860s and Stamsshaw in the 1880s. By the 1950s fifteen more pumping stations had been built to cope with Portsmouth's sewage and drainage. Over that same period the death rate dropped from an excessively high 25.37 per 1,000 in 1851 when the population was 72,000, to one of the lowest for large towns of 18.9 in 1891, when the population stood at 159,251; by 1955, with 238,700 people in Portsmouth, the death rate stood at 10.76, though many other factors had come into play by then.

Disposal of domestic rubbish had been achieved in some towns by using scavengers who dumped the waste material in specified areas away from housing. In many places, however, it was left to rot in the streets. Systematic

collection became widespread in the second half of the nineteenth century, but it was not until the introduction of destructors that there was an alternative to dumping. Even today a large number of local authorities dump their rubbish. The idea of a destructor is a simple one, involving the burning of rubbish at high temperature to destroy all organic matter and reduce it in bulk. A minimum sustained temperature of about 1,250°F is needed to achieve complete combustion of all noxious contents of the waste, and most early destructors fell far short of this. Charles Jones of Ealing, who erected the first destructor near London in 1883, was also the first to grapple with the problem of fumes given off by incomplete combustion, and in 1885 designed what was known as 'Jones' Fume Cremator. This did much to make destructors more acceptable to people living downwind of them, but it was not until forced draught, coke fuel and carefully designed combustion cells were developed in the 1890s that high temperature destruction of all organic material both eliminated the smell and reduced the waste to an innocuous clinker. Today destructors are widely used, and many of them, as examples of late Victorian public health engineering and architecture, could well bear more detailed examination by industrial archaeologists. So too could sewage treatment plants, once called sewage farms, of which numerous early examples are being modernised or replaced, with the destruction of what is frequently first-generation equipment. In towns, manhole covers frequently provide a clue to the type and design of the pipes beneath them and often bear the name or initials of the original authority responsible for construction. An almost completely extinct feature of sewage systems is the sewer gas lamp, built to burn fumes from the pipes below street level. An example of J. E. Webb's 'Patent Sewer Lamp' can be seen in Carting Lane, Strand, London WC2 (160/TQ 305806), and another, from Stourbridge, is preserved in the Blists Hill Open Air Museum, Ironbridge, Shropshire.

#### GAS

The first practical demonstration of the combustible possibilities offered by a mixture of coal gas and air is generally attributed to William Murdock (1754-1839), principal engine erector in Cornwall for the firm of Boulton & Watt. In 1792, the year after he had taken out a patent for a preservative treatment for ships' bottoms that had led him into various distillation ex-

periments, Murdock generated gas from coal and lighted a room in his house in Redruth. Although numerous others had experimented with gas given off by 'cooking' coal in an oven, Murdock's particular and important contribution, on which the beginnings of a practical gas industry were founded, was his systematic investigation of the comparative behaviour of different classes of coal under conditions of varying temperature and times of carbonisation. Although there was little immediate interest in Murdock's experiments, news of parallel work in France being carried out by Philippe Lebon (1767-1804), and the active support of the celebrated Manchester chemist William Henry (1774-1836), encouraged him further and he resumed his work in 1801. In the following year he illuminated the Soho foundry of Boulton & Watt to commemorate the Peace of Amiens, and before long the company was marketing commercially a gas-making plant using Murdock's horizontal retort in which to carbonise the coal. Heat from a furnace was applied to the retort through flues, and crude gas rose to be carried away to a vertical condenser, where a jet of water precipitated the tar and washed it into a tar pit. The system was used extensively for lighting factories, whose owners were eager to adopt something more effective than the traditional candles or whale oil lamps.

In 1812 the first company selling gas from a central generating station through mains to independent consumers was formally established. It was the Gas Light & Coke Company, which by 1815 had built more than 26 miles of underground mains in London. By then gas was being made in tapered horizontal retorts, charged and discharged by scoops, long-handled shovels and rakes and purified by passing it through water to which lime had been added. After purification, a somewhat imperfect process until the 1840s, gas was transmitted through iron street mains to houses, factories and many public buildings, where initially it was used exclusively for lighting. Early gaslights can still be found with ceramic 'fish tail' burners on which the gas burned as an open wall-flame. Not until the 1840s was air mixed with gas to achieve more efficient combustion; the most obvious and familiar example of this was introduced by the chemist R. W. Bunsen (1811-99) in his Heidelberg laboratory in 1855. In the 1860s gas became more widely used than merely for lighting with the introduction of the water geyser in 1865, the gas ring in 1867 and the gas fire with radiants in 1880. Gas cooking was not common until the 1870s, and gas for heating houses on any-

thing like a large scale did not become established until the early 1900s. By then the traditional stronghold of gas—lighting in streets and buildings—was being threatened by electric-arc and incandescent filament lamps, which were introduced commercially in the mid-1880s. The invention in 1885 of the incandescent gas-mantle by the Austrian Carl Auer von Welsbach (1858–1929) enabled gas to hold its own and survive well into the mid-twentieth century, particularly in streets and railway stations, where lamps can still occasionally be found. To the industrial archaeologist gas-burning equipment offers an area of study worthy of energetic pursuit, as the rapid change-over from coal-produced gas to North Sea natural gas is resulting in the elimination of almost all equipment more than about 10 years old.

Similarly the conversion to natural supplies of gas has almost completely eliminated the traditional gasworks, and there are now very few carbonising plants in Britain. The basic processes of coal gas manufacture are still the same, comprising the destructive distillation of coal of low ash content in retorts which in most works today are vertical and mechanically charged. Gas from the retorts passes through various cleaning processes in which by-products such as coal tar and ammonia are recovered in 'washers' and 'scrubbers'. The gas is then pumped, using an 'exhauster', to a gasholder before being distributed to consumers at a controlled pressure. The approximate composition of piped coal gas is usually 55 per cent hydrogen, 30 per cent methane and 10 per cent carbon monoxide, with small quantities of other gases.

Although coal-gas manufacturing equipment is rapidly disappearing, a few plants are still active. Some of these, like the gasworks at Biggar in Lanarkshire (68/NT 039377), are very small, with hand-fired retorts (Plate 60) and one gasholder. Gasholders, often misnamed 'gasometers', still have a storage role and are a familiar feature of many townscapes. The earliest gasholders were thought to present a danger from explosion, and gas companies were required to encase them in brick buildings. This curious idea, which in the event of a mishap would presumably have made every brick a projectile, was soon abandoned, and the riveted iron-plate cylindrical gasholder much as we know it today emerged to become one of the symbols—together with slag heaps and factory chimneys—of everything that was undesirable in the industrial landscape. Some early gasworks have a curious charm, like the one at Fakenham in Norfolk (125/TF 919293), which, it is

60 Hand-firing retorts at Girvan Gasworks, Ayrshire



hoped, will be preserved, or the other, already noted, at Biggar. What is probably the earliest surviving gasholder anywhere is at Fulham Gasworks, Sands End Lane (170/TQ 260768), dating from the 1830s. Another early example, with large spoked wheels over which the guiding chains roll, is at Dolgellau, Merionethshire (116/SH 729179). All these early gasholders consisted of cylindrical inverted 'bells' supported by gas pressure and sealed by water at the bottom. Later several sections of cylinder were telescoped one within another, a huge frame of cast-iron pillars and lattice girders acting as a support and guide. The No 3 gasholder at Fulham was a fine early example of ornate iron framing, and a later and very large example may be seen at Reading beside the River Kennet, near its junction with the Thames (169/SU 731738). Later gasholders dispensed with the fixed guides on pillars and worked with spiral rails on the side of each telescoping section or 'lift'. With the exception of preserved plant—assuming that Fakenham

gasworks is preserved—the gasholder is likely to be the only item associated with the manufacturing side of the coal-gas industry that will survive in use.

#### ELECTRICITY

Today we take electricity so much for granted that it is difficult to imagine life without it. Not only is electrical energy fundamental to the standard of living of us all but it is also the major source of power for industry. Electric power has almost completely freed industry from the locational factors of the past, which tied it to streams and rivers for water power or to the coal-fields when steam was the major prime mover. Though a few activities such as aluminium smelting, which consumes vast quantities of electricity, tend to be deliberately located near the point of generation or to generate for their own use, to almost every other industry, availability of an electricity supply is taken for granted. As with gas, the provision of usable electrical energy is a four-stage process comprising transport of fuel to the generating station, generation, transmission and consumption. Also like gas, the first electricity generating stations were mainly privately owned, of relatively small scale and located near their markets. The creation of a National Grid in the 1930s by which all power stations were linked, the nationalisation of the electricity generating industry in 1948, and, above all, the enormous increase in scale of generating plant, has made it much more economical to locate power stations near the fuel source (usually coal) and transmit over long distances by overhead power line. Thus the power axis of the country has developed along the valley of the River Trent, with a string of large base-load stations close to the East Midlands coalfield. The location of nuclear power stations is governed by different factors, as the transport cost of fuel is negligible. Those so far commissioned in Britain are, in effect, market-located in that they are in coal-deficient areas. With the exception of Trawsfynydd in North Wales, they are located on estuarine or coastal sites, for like traditional power stations they use steam turbines that need condenser coolant water. For reasons of safety, however, in the event of an accidental discharge of radioactive waste, nuclear power stations also tend to be sited in fairly remote areas. The other form of electric power, hydro-electricity, in which water turbines drive the generators, has been little developed in England, although there are plants in Scotland and in North

Wales. The North Wales scheme, at Blaenau Ffestiniog, works in conjunction with Trawsfynydd nuclear power station. It is not possible easily to store high voltage electricity to meet the peak loads on power stations, but water can be stored, so that the hydroelectric station generates during peak times, while in the off-peak period the nuclear power station pumps water from a lower lake back to the upper one in readiness for the next peak period. This scheme allows the nuclear station to work at a very high load factor and at the same time makes available some 300mW of hydroelectric generating capacity for peak demand periods.

The electricity industry offers the industrial archaeologist some important remains at both the generating and consuming end of the energy chain, although for an industry which is so relatively new much in the way of equipment has already gone. The rapid rate of development of the technology of power generation, the changeover from direct to alternating current for consumers, and the postwar boom in efficient electrical appliances in the home has made almost any piece of electrical equipment more than 30 years old of historical interest.

The basis of all electrical power generated by mechanical means, as opposed to electrochemically in a battery, derives from the work of Michael Faraday (1791-1867), and was first demonstrated in 1831. On 17 October of that year he plunged a bar magnet into a coil of wire and generated, in his own words, 'a wave of electricity', and 11 days later he rotated a copper plate between the poles of a magnet and found that a current could be taken from the axis to the rim of the disc. Faraday's original experiment of holding the coil of wire stationary while varying the magnetic field forms in essence the basis of today's large power stations, although the bar magnet has been replaced by an electro-magnet and the coils are so arranged that their windings are cut by the magnetic field as the magnet rotates. Thus the mechanical energy required to turn the magnets is converted into electrical energy in the windings.

By the mid-1830s E. M. Clarke of London was manufacturing hand-powered generators on a commercial basis, but it was not until E. W. von Siemens (1816-92) took out a British patent for a two-pole shuttle armature in 1856 that a satisfactory small generator was available in Britain. In 1866 Henry Wilde and S. A. Varley in England and von Siemens in Germany had devised generators with electro-magnets and self-excited fields to

create what they called 'dynamic electricity', meaning electricity generated by rotary motion. In the following year Charles Brooke (1804-79) used the compound term 'dynamo-electric' to describe all machinery which converted mechanical into electrical energy. The first dynamo of practical dimensions and capable of producing a continuous current was developed about 1870 by the Belgian Z. T. Gramme (1826-1901), and 3 years later the Gramme Company was able to supply a machine for public trial at Westminster, where it powered arc lights. Manufacture in Britain of a superior type of generator, developed in Switzerland by Emil Burgin, was carried out in the early 1880s by R. E. B. Crompton (1845-1940), who built over 400 of them. The first electricity for public electric lighting, at Godalming, in Surrey, in 1881, was, however, generated by a waterwheel, Taunton was another town that had an early public supply.

Crompton was one of the pioneers in Britain of commercial electric lighting using arc lamps in which a continuous electrical discharge was induced between the tips of two carbon rods. Initially his self-contained lighting units, consisting of a portable steam engine driving a generator by belt and powering a number of lights, were used for agricultural shows and fetes, but later they were installed in railway stations, the General Post Office in Glasgow, where two arc lamps replaced 180 gas jets, and in 1882 at the Mansion House in London. Here a combination of arc lamps and incandescent bulbs, developed by Joseph (later Sir Joseph) Wilson Swan (1828-1914) in Newcastle-upon-Tyne, was used. The incandescent filament lamp devised by Swan consisted of an evacuated glass bulb in which a current-carrying filament continuously glowed; although not as bright as the arc lamp, it was reliable and more suited to domestic applications. Almost simultaneously Thomas Alva Edison in the United States invented a similar lamp, which he patented in Britain. Subsequently Edison and Swan amalgamated and formed the Edison & Swan United Electric Light Company later known as the Ediswan Company, registered in 1883 with a capital of £1m. The factory established by Ediswan at Ponders End, Enfield, in 1886 has recently been redeveloped and virtually all the original buildings have gone. Fortunately the site was surveyed in 1969 by Enfield Archaeological Society. Incandescent lamps rapidly became popular and in 1881 were used in the House of Commons, on the Inman liner *City of Richmond*, on a train from London to Brighton, and in the Savoy theatre, where the stage was

lit by 824 lamps, with a further 370 elsewhere in the building.

All these early installations had their own generators, but in 1882 the Edison Company opened its Holborn Viaduct generating station, initially to provide current for street lighting but later extended to serve private consumers. In 1887 the London Electric Supply Corporation was founded to put into effect a huge scheme devised by S. Z. de Ferranti (1864–1930), who believed that the satisfactory development of electric power hinged on generation in quantity. The power station, at Deptford (161/TQ 374779), was designed by Ferranti himself and included two alternators designed for 5,000V and powered by 1,250hp steam engines, and four with 10,000V windings coupled to a single 10,000hp engine. The first current was transmitted from Deptford in 1889, although the station was not in regular use until 1891. Today Deptford power station (Plate 61) is much altered from its first form, though most of the original buildings survive, and as such it is one of the earliest monuments of the electricity supply industry.

Throughout the 1890s power stations, usually relatively small, were built in many British cities by the newly formed electric light companies or to provide light and also current for street trams. Frequently one power station served both functions. In Bristol the original Central Electric Lighting Station building of 1893 (156/ST 594728) still survives on Temple Back, and across the road on Phillip Street is the Bristol Tramway Company's

61 Turbine hall, Deptford West power station, south-east London



power station building (156/ST 593729), built in the early 1900s. The latter is particularly interesting as one of the few stations in Britain built on the space-saving American principle, with its boilers on a floor above the engines and generators.

All these early power stations used reciprocating steam engines with either belt drive to the generators or in some cases direct-coupled crankshafts. The central-valve engine developed by P. W. Willans (1851-92) in the mid-1880s was the most widely used type, although by 1891 Bellis & Morcom of Birmingham were manufacturing smaller enclosed-crankcase high-speed verticals with forced lubrication that were ideal for generating work. Many of the latter can still be found, mainly dating from the 1920s and 1930s, generating electricity in hospitals. The problem with the reciprocating steam engine was developing sufficient speed to power a generator efficiently. The answer was the steam turbine, which was widely adopted soon after it had been invented by C. A. Parsons (1854-1931) in 1884. Today power stations use basically the same arrangement as that devised by Parsons, the steam turbine being direct-coupled to the alternator.

Initially most power stations distributed direct current on a two-wire system at 110V. This was later changed to a three-wire system at 220V offering 110V between each outer wire and the middle wire. As systems expanded, it was found necessary to raise the voltage to 440 and 220 respectively, with electric lights operating at the lower voltage and the larger electric motors connected across the 440V wires. As the number of consumers grew, the current flowing in the mains became heavier, the mains themselves became longer and loss of power through voltage drop reached serious proportions. The answer, originally proposed by Ferranti, was to transmit high-voltage alternating current with minimal losses and to break down the voltage to consumers' requirements at local sub-stations and transformers. This system is the basis of our modern electricity supply network based on a National Grid of 400,000 and 275,000V. The area electricity boards distribute within their areas at 132,000V and below, reducing to 33,000V for heavy industry, 11,000V for light industry and 415/240V for farms and domestic users. National Grid lines are almost invariably carried on pylons for cheapness, although occasionally, as in the Wye valley, they may be underground to preserve scenic amenities. At 11,000V power is generally carried on wooden poles in country areas or underground in

## TOWNS.

The industrial archaeology of the electricity industry illustrates the irrelevance of absolute age when examining the historical significance of a site, a process or a piece of equipment. It is the degree of obsolescence which matters and, in an industry changing as rapidly as electricity generation and supply, obsolescence can occur very quickly. In 1948, when the generating industry was nationalised, some 300 power stations supplied a maximum load of about 10,000mW. Today four times that load is supplied by less than 200 stations, and only two or three new ones are required each year compared with more than twenty that would have been needed under the technology of 20 years ago. Thus operating power stations of the 1920s and 1930s are almost primeval in terms of today's industry, and even stations built as recently as the late 1950s may only be used for peak loads. Few pre-war stations have their original turbines or generators, but a number have been re-equipped, with the result that it has been possible to retain the buildings. Many of these stations, erected by the old private supply companies, had distinctive architectural styles and detailing and, being built in a period of general depression, represent some of the few large-scale examples of building and engineering design of their period. The most distinctive feature in the majority of modern power stations is the hyperbolic concrete cooling tower, which enables condenser coolant water to be returned to source, usually a river, at an acceptable temperature. The first concrete cooling towers in Britain still survive at Lister Drive power station in Liverpool (100/SJ 387917); they date from the mid-1920s and appear minute by the standards of their majestic Trent valley successors. Other early towers may be seen at Croydon 'A' power station.

Efforts are now being consciously made to preserve aspects of the electricity supply industry, and a museum may eventually be set up to preserve important items of generating, transforming and transmission equipment. Numerous existing museums contain small electrical items such as early dynamos, motors, lighting and switchgear. Appropriately one of the largest collections is in the Newcastle-upon-Tyne Museum of Science & Engineering, where the work of C. A. Parsons, J. W. Swan and A. C. Reyrolle is well represented. Here, insulators, sections of cable, arc lamps and early incandescent bulbs abound. The most comprehensive range of material, however, is in the Science Museum, South Kensington.

## URBAN TRAMWAYS

The availability of electricity and of efficient electric motors encouraged a mode of transport that had been developing since the 1860s in a number of British towns. Initially horse-drawn, the street tram had been introduced from the United States to Birkenhead in 1860 by George Francis Train, who laid a 3ft 2in gauge line with flanged rails from Woodside Ferry to Birkenhead Park, then a fashionable residential area. Other lines followed, including a route in London from Notting Hill Gate to Marble Arch, but most had been removed by 1862, largely because of the damage the up-standing edge of the 'step rail' was causing to the tyres of horse-drawn carriages. However, grooved rails and flanged wheels were substituted in Birkenhead and on another line in the Potteries, and proved highly successful. By the late 1860s the horse-drawn tram was becoming accepted as an efficient means of moving people in town streets, where a pair of horses could haul a tramcar seating forty-six and having the low rolling resistance of the rail-borne vehicle, while the traditional bus with two horses was limited to about twenty-six seats. There is little material evidence surviving today of the early period of tramway development, although Hull Transport Museum has a single-deck horse car of the type used by Train which was built in 1867 and ran on Ryde pier in the Isle of Wight.

Legislation allowing the widespread growth of street tramways came with the Tramways Act of 1870, which, in terms of the development of efficient and coordinated systems, was something of a mixed blessing. Two clauses in particular penalised the new tram-operating companies. Not only did they have to lay and maintain their own tracks but they were also responsible for the road surface between the rails and for 1ft 6in on each side of them. In addition the local authority had the power to purchase the whole system after 21 years, a right which then recurred every 7 years. This, not unnaturally, discouraged the tramway operators from installing expensive new capital equipment, for much expenditure would immediately make their takeover more attractive. The ultimate result of this bizarre state of affairs occurred in Bristol, where primitive open-top double-deck trams were still in use until the early 1940s, when they were replaced by buses. Bristol is still the only major British city without municipally owned transport.

Generally speaking, tramways were taken over by local authorities in the late nineteenth and early twentieth centuries, although by then it was

often too late to develop any integrated inter-urban system on the American pattern because of gauge variations, though a surprisingly wide coverage was attained in Britain. By far the most popular was the standard 4ft 8½in used on railways although an ingenious variation found only in Glasgow, Huddersfield and Portsmouth involved a gauge of 4ft 7½in. The reason for this was that conventional railway wagons could be run on the street tram tracks, thus giving them access to numerous industrial undertakings not normally enjoying a rail connection, but as the depth of flange on a railway wheel is greater than the depth of groove in a tram rail and the width of wheel tread substantially wider, the ½in reduction in gauge allowed railway wagons to run on their wheel flanges along the flangeways of tram tracks. Elsewhere narrower gauges were used, 3ft 6in being universal in and around Birmingham and 4ft in the Potteries and north Staffordshire. One of Birmingham's narrow double-deck electric cars is preserved in the Birmingham Museum of Science & Industry, Newhall Street, Birmingham 3.

In 1879 mechanical power was permitted for trams under the Use of Mechanical Power on Tramways Act, but such severe restrictions were imposed for the protection of other road users, human and equine, that really imaginative developments were stultified at source. Despite the fact that 10mph was the maximum permitted speed, that all working parts had to be concealed from view and that machinery had to be practically silent, with no visible emission of smoke or steam, firms like Merryweather and Kitson produced reasonably successful steam engines for pulling trailer cars. A preserved example, from Portstewart in Northern Ireland, can be seen in Hull Transport Museum.

Electrification came in the 1880s in an experimental way and by the late 1890s had proved itself beyond all doubt as the best means of powering tramcars. At the start of large-scale electrification, in the late 1880s, there were some 800 route miles of tramway in Britain, and this had increased to 1,040 by 1900, the larger part still being horse- or steam-worked. Between 1900 and 1907 electric lines boomed and a total route mileage of 2,530 had been reached by the outbreak of World War I, the high point of the tramway era.

American practice considerably influenced the widespread development of electric tramways in Britain, although most of the initial experimental

work had been carried out in Germany by engineers such as Werner von Siemens and Magnus Volk. Volk came to Britain in 1883 and built a 2ft 8½in gauge electric railway along the seafront at Brighton from the Aquarium (182/TQ 316038) to Black Rock. This odd little line, which still runs, represents the first use of electric traction in Britain. Street trams proper operated at about 600V DC, with current usually supplied to one (positive) wire and, after passing through traction motors and lighting, being returned to the power station through the (earthed) track rails. Trams had four wheels, with two axle-mounted motors, but later large eight-wheel bogie cars were introduced, notably in London, Glasgow and Liverpool. Current collection was usually by trolley poles, but Glasgow and Leeds and some Birmingham routes employed bow collectors, which obviated the needs for complicated pointwork in the overhead wiring. In parts of London a conduit between the rails carried the current.

The period from about 1900 to the outbreak of World War I in 1914 was the golden age of the tram, the first form of urban transport accessible to the mass of the population. It was a harbinger of social change, continuing and developing the work begun by the suburban railway services in enabling people to move easily and cheaply between industrialised areas and their homes in more pleasant surroundings. Every major town had a tramway, and in Lancashire and Yorkshire particularly, end-on junctions of innumerable independent systems enabled the diligent traveller with an eye to economy rather than speed to make quite lengthy excursions. Thus the Pier Head in Liverpool could form the start of a tram journey into the upper Pennines beyond Rochdale by way of St Helens, Atherton, Bolton, Bury and Heywood. Seven miles over the top was Hebden Bridge, terminus of the West Riding network, running eastwards to beyond Leeds and Wakefield. Suburban housing estates developed along tram routes, and cities like Glasgow, Birmingham and Liverpool still reflect their one-time dependence on trams in the wide central reservations of their main road approaches, which once enabled trams to run completely separated from road traffic. It was the incompatibility of the tram with motor vehicles and its lack of flexibility when compared to the bus that led to its decline and eventual extinction. In addition the high cost of maintenance of track and overhead, and the very low operating costs of the diesel bus, which began rapidly to replace its petrol-driven predecessor in the late 1930s, made the tram in its

traditional form largely redundant. A few cities, notably Sheffield and Leeds, began programmes of tramway modernisation, with ideas of developing high-speed reserved-track systems, but changes of management and of political complexion killed these schemes and 1963 saw the last of Britain's trams withdrawn from the streets of Glasgow. Only in Blackpool can a near equivalent still be found, with streamlined single-deck cars operating along the seafront.

An interim phase between the tram and the complete domination of public road transport by the diesel bus has also recently come to an end with the withdrawal of the last trolleybuses in Bradford, which, with Leeds, had been the scene of the first regular services in 1911. Of German origin the 'railless tram' had the attraction of manoeuvrability in restricted town centres, quietness, speed, and in later years remarkable acceleration. Numerous tram systems were abandoned in favour of trolleybuses in the 1920s and 1930s, and new routes were being built well into the 1950s in several cities. Again, however, some of the shortcomings of the tram applied to the electric bus, the cost of overhead wires and pointwork in particular leading to their abandonment in favour of high-capacity diesel buses, now often operated by one man only. Today no trolleybus systems are working in Britain, although at least two operational museums are proposed and individual vehicles are preserved, notably at Bournemouth and Bradford.

Trams have always enjoyed a large enthusiast following, and at Crich in Derbyshire (111/SK 345548) the Tramway Museum Society operates a thriving museum where over forty cars from places as far apart as Glasgow, Sheffield, Southampton, Johannesburg and Oporto are preserved, many of them in running condition. A regular service is operated on a  $\frac{1}{2}$  mile track. Museums with collections of non-operational trams include the Glasgow Transport Museum and the London Transport Collection at Syon Park.

The period from the 1870s to 1914 represented the great age of public transport, and the tram and cheap-excursion train gave millions of people a mobility completely unknown before. Although the tram has disappeared and relatively few people go to the seaside by cheap-day excursion, a surprising number of working reminders of this pre-automobile age still survive. In the Isle of Man horse trams, introduced in 1876, still operate a summer service along the front at Douglas, providing a connection at

the northern terminus with the Manx Electric Railway, a 3ft gauge rural tramway running to Ramsey. This itself connects with another electric line that connects Laxey to the summit of Snaefell. In North Wales a cable-operated 3ft 6in gauge tramway, opened in 1902, runs from Llandudno (107/SH 777827) to the 679ft summit of the Great Orme. Further south the Fairbourne Railway (116/SH 615128) in Merionethshire, a 1ft 3in gauge steam-operated miniature line, occupies the trackbed of a horse tramway opened in 1916 to connect with ferries across the Mawddach estuary.

Evidence of urban tramways is rapidly disappearing, although a large number of bus depots are merely tram sheds with the tracks removed, covered up or, occasionally, left *in situ*. A fine example of the smaller tram shed, with a section of 3ft 6in gauge track in front of it, can be seen near Chester General railway station (109/SJ 413668), while on the forecourt of Ashby-de-la-Zouch station (121/SK 355164) is the terminus trackwork of one of Britain's few real inter-urban lines—the Burton & Ashby Light Railway, operated initially by the Midland Railway and abandoned by the LMS in 1926. In London the Kingsway Tramway Subway (160/TQ 305817), built for single-deck cars in 1905-8 and deepened to take double-deckers in 1930-31, has been partially converted into a two-lane underpass. A rare survivor in Liverpool is a section of horse-tram track in Queen Square (100/SJ 346906) whose unusual features are a centre flangeway with a section of tread on each side (instead of the normal side flangeway) and rail joints made at an angle to reduce noise and wear. In many towns where trams were used in narrow streets the overhead wires were supported from buildings rather than from poles, and the cast-iron wall rosettes from which they hung can still be seen. They were particularly popular in Glasgow. In Liverpool a highly decorative rosette incorporating the city's emblem—the liver bird—can still be seen here and there.

#### MISCELLANEOUS PUBLIC UTILITIES

Numerous other public utilities provide the industrial archaeologist with fragmentary evidence of their development, although generally such evidence is on display in a museum rather than still in use. The introduction of the penny post by Rowland Hill in 1840, the first efficient large-scale postal service in the world, led to the building of post offices in all towns and

many villages, and to cast-iron letterboxes appearing throughout the country. These have for long been objects of great affection, particularly the pillarboxes which appear in a variety of forms and bear several makers' names. The attractive 'Penfold' hexagonal boxes are relatively common, but less so are the dignified fluted pillarboxes found in Malvern, Worcestershire, and the magnificently crowned 'Liverpool specials' introduced in the 1860s to provide additional capacity for newspapers. A good example of the latter still stands on Edge Lane, Liverpool. Railway stations are a good source of early and unusual boxes.

The introduction of the successful electric telegraph in Britain, after many years of experiment, particularly in Germany, resulted from the collaboration of two complementary figures—the far-seeing William F. Cooke (1806–79) and the ingenious Charles Wheatstone (1802–75)—who installed a direct-reading system using five wires along the main line of the Great Western Railway between Paddington and West Drayton in 1839. Deflection of the needles on the telegraph instrument enabled any one of twenty letters to be indicated, but the high cost of laying five wires resulted in two-needle and even single-needle instruments being used on railways, where codes could be used. The best known of these telegraph codes, now the standard, was devised by the American Samuel F. B. Morse (1791–1872). The Science Museum has a fine collection of telegraphic equipment, including a remarkable two-needle instrument in the gothic style for use in the Palace of Westminster. The railways, which benefited directly from the introduction of the electric telegraph, became rapidly transformed in appearance, poles and wires following virtually every line. Indeed the railway was fundamental to the success of the telegraph system, as it could supply ready-made routes, with no problems of wayleaves for poles and wires, along which a nationwide all-purpose communications network could be built. Thus the social changes the railway had helped to create by increasing the mobility of people were furthered by a new demand for the sending of personal messages.

The electric telegraph, perhaps the least recognised but certainly one of the most important nineteenth-century innovations in communication, was not in fact the first form of telegraphic system to be used regularly in Britain. There was, of course, the sixteenth-century system of hilltop bonfires, which gave warning of the approach of the Spanish Armada; and in the 1790s a series of hilltop telegraph stations were built to connect the Admiralty

in London first with Deal and later with Portsmouth, Yarmouth and Plymouth. Initially shutters were used to transmit messages, but semaphore arms later replaced them. Today a number of stations remain, such as that on Chatley Heath, Surrey (170/TQ 089585), built in 1823 to replace an earlier wooden structure. Elsewhere the name Telegraph Hill is a common reminder of the system, while the sign of 'The Telegraph' inn on Putney Heath (170/TQ 233737) illustrates clearly the earlier signalling equipment. The London to Portsmouth telegraph, the last in use, finally closed on 31 December 1847.

The electric telegraph was to a great extent superseded, at first over relatively short distances, by the telephone developed from German experimental beginnings by Alexander Graham Bell (1847-1922) in America and patented in Britain in 1876. The first telephone exchange was established by a private company in London in 1879 and others quickly followed. Inter-urban lines were established and a countrywide network gradually developed, most of it in the hands of the National Telephone Company. In 1912 the General Post Office acquired all private telephone systems, with the exception of one that still operates in and around Kingston-upon-Hull in Yorkshire. The rapid rate of development of telephony, particularly since the introduction of subscriber trunk dialling in the 1950s, has resulted in most early exchange and transmission equipment disappearing, although numerous early handsets survive. Micro-wave transmitting, relay towers and multi-core cables have almost completely eliminated the poles and wires which were a feature, particularly of the Great North Road, in the inter-war period. The telephone kiosk, however, is still a link with the earlier days of the public telephone service, a distinguished piece of industrial design in cast iron by Sir Gilbert Scott (1880-1960), whose better known works include Liverpool Cathedral, Battersea power station and Waterloo Bridge.

The beginnings of modern fire-fighting by an organised fire brigade can be found in the first fire insurance companies set up in London shortly after the Great Fire of 1666. By the end of the eighteenth century almost every town and county had its own insurance company, some of which, as a result of their very direct pecuniary interest in reducing losses by fire, were beginning to operate their own fire-fighting forces. These companies issued plates to mark the properties insured with them, and many plates survive,

illustrating the large number of companies. Fire engines, in the form of horse-drawn hand pumps, were used and numerous examples, mainly dating from the mid-nineteenth century, can be found in museums. An unusual small type of 'fire engine', developed by the Merryweather company, consisted of a manual pump with four carrying handles, which could be used in factories or country houses. An example can be seen in the Glasgow Museum of Transport. The replacement of manpower by steam was an obvious development, but initially this was only for powering the pumps. Throughout the second half of the nineteenth and well into the twentieth century the standard large fire engine, weighing up to 4 tons, was drawn by horses and had its pump powered by steam. Numerous examples of these engines, notably those built by Shand Mason and Merryweather, have been preserved in museums. Although self-propelled steam pumps had been tried, they were too heavy and cumbersome to be a success, and it was not until the early 1900s that the first petrol-driven fire engines began to supersede horse-drawn ones. For a short time petrol-engine-propelled fire engines with steam pumps were used, but before 1910 both road wheels and pumps were being powered by internal combustion engines. Of all the types of public service appliance, the fire engine has had greatest popular appeal, and large numbers are preserved in museums throughout Britain. They can be seen on display at Bristol, Glasgow, Leicester, Liverpool, the London Science Museum and Swindon, to name but a few. In Norwich the Norwich Union Insurance Group has a small museum relating to its work in fire insurance. Early fire stations, some with stables, bell turrets and smoke vents, can still be found, and deserve attention from the industrial archaeologist. The whole technology of built-in systems of the sprinkler type and automatic alarms is another area needing recording and documentation.

## 13 Roads and Bridges

### ROADS

THE development of the road system was intimately tied up with the growth of settlements, and early roads were simply paths from one village to another. They took the easiest, usually the driest, route, avoiding steep hills, dense woodland or land under crops. With the exception of Roman roads and new motor roads mainly built in the last 30 years, almost all the roads along which we travel today have their origin as primitive paths in a period when long-distance overland travel, let alone the wheeled vehicle, was virtually unknown.

A road, theoretically, is not a strip of land, but a right of passage and, during the Middle Ages, the keeping open of a way passable for travellers on horseback and for trains of packhorses was accomplished with varying degrees of success under manorial jurisdiction. As trade increased with the widening of the known world at the end of the fifteenth and the beginning of the sixteenth centuries, it became difficult for the roads to cope with the increasing traffic especially where this increase coincided with the breakdown of the manorial courts. A tenant who had recently secured his freedom from the agricultural and other servile duties imposed by customary law could hardly be expected to agree willingly to an increase in the amount of labour and time he spent on the highways of the manor.

This common law liability on the inhabitants of each parish to keep their roads in good repair was reinforced in 1555 by an Act of Parliament 'for the mending of highways'. Under the Act each parish had to choose annually a surveyor of highways, or waywarden, who was given power to call out the available labour of the village or town to work on the roads for 4 days per year. With various amendments, such as increasing the period of statute labour to 6 days and the granting of powers to levy rates up to 6d in the pound, the 1555 Act remained the basis of highway administration for nearly 300 years.

In some parishes this system worked fairly well. Where the roads of a parish were used by the inhabitants only, they received some attention in

turn, although perhaps not every year. When John Smith was waywarden he would naturally devote most time and labour to the roads he used, and perhaps neglect those used by Thomas Brown. But Thomas Brown would probably be surveyor before long, so things would even themselves out. In some parishes, however, a trunk route between two large towns might follow a parish road, and excessive wear and tear would result. In others a main road might cut across the corner of a parish, and although it would be used by long-distance travellers, its maintenance would still be the responsibility of the parishioners. In these situations the system of parish road maintenance fell into disrepute. On a porous, well drained subsoil heavily used but little cared for roads might stand the strain, but where the soil was of clay the road inevitably became, in the words of the time, 'deep and foundrous'. Stones might be laid on the surface but would soon sink into a sea of mud, to be followed by the wheels that rolled them in. Horses died, bogged down to their shoulders in mud. Roads were in places 60-100yd wide where travellers had attempted to skirt a treacherous area. As many as ten horses or oxen might be required to move a load of 1-1½ tons over heavy ground. In winter, haulage of heavy loads stopped altogether. In the early eighteenth century Daniel Defoe noted that it took 2-3 years to move a large tree trunk from the neighbourhood of Lewes to Chatham dockyard. A few miles would be achieved each summer, with as many as twenty-two oxen pulling the tree on a vehicle known as a tug, but by September the roads would be so soft that the journey would have to be abandoned until the following June.

It was these circumstances, repeated in greater or lesser degree all over the country, that led to the first turnpike Acts, under which tolls could be levied to repair the roads. The principle of making travellers pay a contribution towards the upkeep of the roads and bridges they used had been established as early as the twelfth century, some 400 years before the birth of the turnpike system. Grants of 'pavage' were made for the upkeep of roads and streets, and of 'pontage' for the construction and repair of bridges, usually by the king, to lords of manors or heads of religious houses, enabling them to collect tolls in specified areas. In 1279 Edward I granted pontage for 3 years to the 'bailiffs and good men' of Huntingdon, empowering them to collect tolls for the upkeep of the bridge. The great bridge at Swarkeston in Derbyshire, a fine surviving example of a medieval bridge (121/SK 369285),

was the object of similar grants in the reigns of Edward II and Edward III. These grants may be called the forerunners of the turnpike Acts of later days, but they did not form the genesis of the system.

The first turnpike road resulted from an Act passed in 1663 empowering the justices of Hertfordshire, Huntingdonshire and Cambridgeshire to erect a gate in each county and levy tolls on the Great North Road. No further turnpike Act was passed until 1695-6 when Acts for the London to Harwich road and a section of road between Attleborough and Wymondham near Norwich were placed on the statute book. Increasing numbers of Acts followed in succeeding years, but 1706-7 established a precedent that was to become standard for all future turnpike roads. Instead of the local justices being empowered to become the road authority, a body, consisting usually of local gentry, was set up to act as turnpike trustees. In all cases where a road was turnpiked the initiative was local. Parliament did not decide that certain stretches of highway were more in need of extra care than others, but local people, interested in certain parts of the roads, formed themselves into committees, subscribed the legal expenses, petitioned Parliament, and, having obtained their Acts, became the trustees.

The key to the functioning of a turnpike trust was its power to raise tolls. At first toll lists were simple, but they gradually became more and more complicated as differential charges were introduced and various restrictions and allowances were made for wheel width, wheel construction, weight of lading, and number of draught beasts. On a few points there was general agreement between one trust and another. No tolls were levied on foot travellers, and tolls charged by the Acts were maxima, which could be lowered, but not raised, at the discretion of the trustees. The charges for horses, without vehicles, whether led, driven or ridden, varied between  $\frac{1}{2}$ d and 2d each. Cattle were generally charged 10d per score, and sheep and pigs 5d. The greatest variation occurred in the schedules of charges for vehicles, some forty separately identifiable goods and passenger vehicles appearing in the toll lists of the various Acts. In 1753 an Act prohibited the use of wagons with wheels less than 9in wide, unless drawn by oxen or less than five horses, and 2 years later another Act allowed 3 years' exemption from tolls for wagons with 9in wheels. In 1765 preferential treatment was given to wagons with the fore wheels on shorter axles than the rear wheels, on the grounds that a greater width of road would be effectively rolled,

and in 1774 wagons with 16in wheels or rollers were given complete freedom from tolls for 5 years.

The period 1750-80 saw the greatest geographical expansion of turnpiking, although mileage increased at a slower rate down to the late 1830s. At this peak period most main roads, especially in England, were under the care of nearly 4,000 trusts whose responsibility covered some 22,000 miles of road out of an estimated total of 105,000 miles. Turnpikes were most numerous in heavily populated industrial areas, counties such as Suffolk and Essex having only some 10 per cent of their roads under trust maintenance. All other roads were still, of course, the responsibility of the parishes, and were generally in a poor state. It was not until 1835, after nearly 300 years, that the statute labour basis of maintenance was replaced by a rating system, with parishes formed into districts each covered by a district surveyor.

Throughout the eighteenth century highway legislation had been based on the supposition that it was impossible to keep roads in good repair without restrictions on the types of vehicle using them. Hence the idea prevailed that carts and wagons could be so constructed that they repaired rather than damaged the roads, with consequent agitation for broad rollers rather than wheels. At the root of all this was a fundamental lack of knowledge of any systematic or scientific approach to the construction or maintenance of the roads themselves. Credit for the introduction of new roadmaking techniques which, as the timings of the mail coaches indicated, revolutionised road travel, must go to three men—'Blind Jack' Metcalf, John Loudon Macadam, and Thomas Telford. John Metcalf (1717-1810) was born at Knaresborough, Yorkshire. He had been musician, jobmaster, fish dealer, recruiting agent, hosiery merchant, horsedealer, and possibly trader in smuggled tea before he took up roadmaking, with a contract to build some 3 miles of the Boroughbridge to Harrogate road, turnpiked in 1765. Blind from the age of six, Metcalf had an uncanny ability to assess the lie of the land and determine the most favourable route across it, gaining a picture by extensive walking or riding. When he retired in 1792, he had improved some 180 miles of road for a score or so of trusts in the West Riding of Yorkshire, south Lancashire and north Derbyshire. Metcalf was the first of the great road engineers to appreciate the need for a well drained, firm foundation. A smooth convex surface of stone and gravel was laid over bundles of ling or heather set on a foundation of prepared subsoil. Ditches

on either side of the road, which was elevated between them, ensured the surface would be free-draining. This was a great advance in roadbuilding technique over contemporary practice, and although the amount of road he improved was relatively small, Metcalf's contribution was of fundamental significance.

Macadam (1756-1836) and Telford (1757-1834) were almost exact contemporaries whose chief work dates from a little later than that of 'Blind Jack'. Macadam's name is associated with the system of road surfacing using broken stone instead of gravel rather than the variations of his method that bear his name today. His plan was as follows: 'Now the principle of road-making I think the most valuable, is to put broken stone upon a road, which shall unite by its own angles, so as to form a solid hard surface.' This material, no stone of which was to exceed 6oz in weight, was to be laid to a depth of about 10in and be well consolidated. He did not care particularly what lay underneath, arguing that a subsoil base drained by side ditches and protected from rain penetration by a sound surface would support any weight. Great care had to be exercised in breaking stone for Macadam's roads. He insisted that surveyors trained in his system should be equipped with a pair of scales and a 6oz weight, or a zin metal ring through which the stones had to pass. A 6in layer of these angular stones was laid as evenly as possible, followed by a further 6in some weeks later when the first had consolidated under traffic. A surface 18ft wide cost in the region of £88 per mile.

The relative cheapness of the Macadam system led to its adoption by the majority of turnpike trusts. By the late nineteenth century 'water-bound macadam' road was almost universal throughout Britain, and the name of its inventor had become part of the English language. Macadam himself became surveyor of the Bristol Trust in 1816, and by 1819 the 180 miles of road of this largest turnpike trust in the country were already well known for their admirable state of repair. The fact that, once improved, a macadamised road demanded much less maintenance than other roads attracted many trusts. Macadam was appointed Surveyor-General of the Metropolitan roads in 1827, and he and numerous members of his family advised dozens of trusts up and down the country in succeeding years.

Thomas Telford was one of the great civil engineers of his generation, a famous bridge and canal builder but mainly memorable perhaps as an

improver of roads. The son of a shepherd and trained originally as a stonemason, Telford was appointed Surveyor of Public Works for Shropshire in 1787. Besides undertaking a prodigious programme of bridge building, he gained wide experience of road work both in Shropshire and, later, in the Highlands of Scotland, where he built or improved many hundreds of miles of road as part of a scheme to bring life back to that depressed and depopulated region. Telford's system of road construction was similar to that developed in France in the 1770s by Pierre Trésaguet (1716-94). It consisted of laying a solid course of large stones on the prepared and level bed of the road 'in the form of a close neat pavement'. Over this was laid a 6in spread of hard broken stones, each as nearly cubical as possible, and on top of this again a 2in top layer of gravel. Great care had to be taken in laying the stone foundation and in applying the top surface of gravel, with its precisely specified 1 in 60 fall from the crown to the sides of the road. The cost of Telford's roads was relatively high because of the heavy foundation, and as a result they did not find as much favour as Macadam's 'elastic' system.

Nevertheless in 1815, when the Holyhead Road Commission was set up, Telford was called on to survey the route and engineer a new and efficient road out of the chaotic situation administered by no less than twenty-three separate turnpike trusts. South of Shrewsbury the major improvements consisted largely of easing gradients and building short by-passes to avoid narrow sections in villages. In Wales, however, a much more radical approach was needed, and the road as it stands today is a remarkable tribute to Telford's engineering skill. West of Bettws-y-Coed the existing route wound north along the Conway valley and then west beside the coast to Bangor. Even today the section of this old road through the Sychnant Pass (107/SH 750770) between Conway and Penmaenmawr is formidable; to the early mail coaches it was often impossible. Telford surveyed a new route westward from Bettws-y-Coed that included a winding ascent up the valley of the Llugwy to Capel Curig, a spectacular feat of road engineering rendered almost ordinary by the section which follows—from Llyn Ogwen through the Nant Ffrancon Pass. Here, without involving a gradient steeper than 1 in 22, Telford carefully edged his alignment up the steep side of the glacial valley towards its head. This is the real civil engineering that distinguished Telford from most contemporary road improvers, who did little more than

remodel the surface of the existing alignment.

It is worthwhile reviewing the impact of turnpiking, its decline, and the remains of the turnpike era the industrial archaeologist can find on the ground today. Despite the obvious benefits, the new restrictions of gates on the 'King's Highway' were not without opposition and riots occurred in a number of places. Around Bristol in the 1730s and 1740s colliers from south Gloucestershire and farmers from north Somerset destroyed gates and burned tollhouses. In South Wales, too, farmers resisted turnpiking with force as late as the 1840s. This was the period of the 'Rebecca Riots', when gangs of small farmers, whose hardships resulting from economic depression were aggravated by the tolls, roamed Pembrokeshire and Carmarthenshire destroying the tollgates. The mob was usually led by a man in woman's clothes, named after Isaac's wife 'Rebecca' from *Genesis*, who receives the promise that her seed should possess the 'gate' of those who hate her. These local difficulties were usually shortlived, however, and the increasing number of travellers and carriers had by the 1820s, when Macadam's and Telford's improvements had become widespread, every reason to bless the new roads and their superior surfaces. For the first time for nearly 2,000 years the speed of long-distance land transport in Britain was limited by the capacity of the horse rather than the condition of the road. In 1784 the introduction of tightly scheduled mail coaches permitted the traveller to reach Birmingham from London in 12hr and Exeter in 17½hr. By 1834 English coaches drove at an *average* speed of 9-10mph, only the severest winter weather causing dislocation of their services.

Generally speaking, it was not until well into the railway era that the turnpike trusts began to suffer financial difficulties, and at first some of them actually benefited from traffic attracted by the new lines. By the late 1840s, however, some trusts were appealing to the local justices for rates to be levied for the upkeep of roads, and in 1851 insolvent trusts were allowed to apply to the Secretary of State for provisional orders to reduce interest and extinguish arrears. Throughout the 1860s, 1870s and 1880s, the turnpike system was abolished as the various Acts expired. Most of these Acts were for specified periods, usually 21 years, and then subject to renewal. After 1831 this renewal became automatic under the terms of the Annual Continuance Acts, which extended for 1 year all Acts due to expire. An increasing number of trusts asked for their Acts to be excluded from the annual continuance process

and in 1895 the last turnpike Act expired. The system had taken 232 years to grow, flourish briefly, and expire, and with its expiry came something of a decline in the standard of rural roads.

Visible evidence of turnpiking is still surprisingly common throughout much of Britain. Nothing much survives of the toll roads themselves, although occasionally road works may reveal an early nineteenth-century surface buried in the foundations of its modern counterpart. Similarly, and for obvious reasons, the gates have disappeared. There are, however, many hundreds of tollhouses and milestones and, here and there, signposts also. Most tollhouses date from the early nineteenth century, and frequently have a form which makes them instantly recognisable (Plates 62 and 63). The half-hexagonal end with windows giving a view in each direction down the road, the hipped roof often with a prominent overhang to the eaves, and the area of wall above the central window where the tollboard would originally have hung, are all typical features. Few tollhouses still have their boards. Notable examples which do are to be found at Steanor Bottom Bar, Todmorden in Lancashire (101/SD 945198) at the junction of Calderbrook Road and Rochdale Road, and on the Holyhead Road at Llanfair PG, Anglesey (107/SH 532715). The latter, a Telford tollhouse, has the veranda that typified a number of his other tollhouses and appeared less frequently

62 Tollhouse at the east end of Mythe Bridge, Tewkesbury, Gloucestershire





63 Tollhouse at Keswick, Cumberland

elsewhere, as at Ashton Gate, Bristol (156/ST 573717). A slate tollboard from a demolished tollhouse is mounted beside the A6(T) at Shardlow, Derbyshire (121/SK 442303); nearby are the abutments of the bridge across the Trent, swept away by floods in 1947.

The erection of milestones was a statutory responsibility of the turnpike trusts, although as early as 1698 parishes had been required to put signposts at crossroads. Few of these latter survive but long runs of milestones can still be seen, often beautifully maintained by the county highway authorities. Many trusts had distinctive patterns, Telford designed his own milestone for the Holyhead road—a chamfered tapering stone with a cast-iron plate. Others were made entirely of cast iron and frequently had a 'V' plan to make for ease of reading. A fine example by I. & F. Thornewill of Burton-on-Trent, dated 1828, is on show at the Staffordshire County Museum, Shugborough (119/SJ 991224), one of a series on the A50(T) between Uttoxeter and Newcastle-under-Lyme, of which many survive *in situ*. Numerous examples of the similar iron posts erected by the Bristol trust can be seen along the A38(T) between Bristol and Bridgwater. A distinctive cylindrical type (Plate 64) again in cast iron, occurs frequently in Derbyshire, the roads from Leek to Buxton and Ashbourne each having a substantially



BY LONDON  
119  
MILES

64 Cast-iron milepost at  
Shardlow, Derbyshire

complete series. Signposts are less common, but notable examples include the very fine cast-iron Doric finger post in Bristol at the junction of the Bath and Wells roads (156/ST 599718) and the stone obelisk at Craven Arms, Shropshire (129/SO 433827). Although these early signs are reasonably safe from destruction, more recent examples, erected in the present century, are now becoming extremely rare and will almost certainly disappear with metrication and the adoption of international symbols. Even rarer survivals of the turnpike era, however, are the vehicle weighing machines introduced after an Act of 1741 put a levy of extra tolls on carts and wagons laden beyond certain specified limits. One at Woodbridge in Suffolk (150/TM 272491), operated on the steelyard principle, may owe something to the work of John Wyatt (1700-66), a prominent designer of weighing machines. The Woodbridge machine (Plate 66), mounted on the end wall of 'Ye Olde Bell and Steelyard', is suspended by a hook from a large pulley-block which is itself suspended from another block housed under a small roof. A small wooden platform is attached to the massive cantilever bracket that carries the steel yard, to enable the weighman to adjust the lead weight or poise and



65 Cast-iron road sign erected in 1913 by the Cheshire Automobile Club, Prenton, Cheshire

so effect a balance. The yard is some 20ft long but the load and fulcrum centres are only 2½in apart.

Although the introduction of motor vehicles brought about a new revolution in road construction, various attempts to improve on macadamisation were made in the nineteenth century. Tar was applied as early as 1845 in Nottingham and in the 1870s in Sheffield and Liverpool. Asphalt, a naturally occurring bitumen from Limmer in Hanover and later from Lake Asphalt in Trinidad, was also used, initially for paving and subsequently for road surfaces. Tar spraying of macadam roads was widely adopted as a way of combating the dust caused by the suction effect of rubber-tyred vehicles. Road surfaces in towns were generally made of granite setts after the 1830s, and huge quarries in Scotland, North Wales and Chamwood Forest, Leicestershire, were opened to supply the stone. Laid initially on sand and after about 1870 on concrete, these setts are still common, particularly in side streets. Sometimes they are laid in a fan pattern, as on the cab rank of Manchester Central station (101/SJ 837977). Wood blocks, with their advantage of quietness, were used in many towns from the 1840s down to the

66 Wagon-weighing machine based on the steelyard principle, Woodbridge, Suffolk



1920s, but have now almost completely disappeared. Special tracks for carts and wagons were frequently installed in dock areas. These consisted of large, well fitted blocks of granite laid railway-fashion in two lines to match the distance between the vehicle wheels, and separated by a band of ordinary setts. In 1825 they were laid in Commercial Road, London; a length in Exchange Street East, Liverpool, where the stones are known as 'wheelers', can still be seen.

Despite the massive modernisation of roads in recent years, they still provide a fruitful source of interest for the industrial archaeologist. Cast-iron kerbs and gullies, bollards and street signs survive in profusion, as in High Street, Dorking (170/TQ 166495), and more recent signs, often vitreous-enamelled, erected by the Automobile Association, Royal Automobile

Club, Cyclists' Touring Club and the various petrol companies etc, can still be seen though in rapidly declining numbers.

#### BRIDGES

From the industrial archaeologist's point of view bridge building, so intimately connected with the turnpike road movement, is a profitable area of study. In the mid-eighteenth century bridges were still the exceptional way of crossing large rivers, and many of those that did exist were of medieval origins and too narrow for horse-drawn vehicles. Fords and ferries predominated, and a large river like the Yorkshire Ouse, although having some twenty ferries, had only one bridge. Indeed it was not until 1888 that there was a general statutory obligation for public authorities to build bridges. A few bridges were maintained before 1750 by county quarter sessions or hundreds, but most were repaired by ancient and often inadequate endowments. The General Highway Act of 1773 allowed magistrates to make indictments in respect of bridges, which meant that counties were ultimately held responsible for upkeep. In Scotland the state-aided Commission for the Highland Roads, established in 1803 and with Thomas Telford as engineer, built some 1,200 in 25 years. With the rapid increase in traffic brought about by turnpiking, and the demand for shorter routes, a period of major bridge construction began in the latter years of the eighteenth century.

All bridges are based on one or more of three fundamental structural forms: the beam, of which the slab of rock or fallen tree trunk are the simplest forms; the arch, in which the deck is supported by a structure of wedge-shaped arch stones or voussoirs; and suspension, in which the deck is hung by suspenders from a continuous cable. In eighteenth-century Britain all important bridges were of the arch type, constructed on the empirical evidence available from earlier bridge builders and from buildings such as the great medieval cathedrals. At this period the first theories of arches were developed, notably in France where the Corps des Ingénieurs des Ponts et Chaussées under the guidance of Jean Rodolphe Perronet (1708-94) was applying scientific techniques to constructional problems. In Britain Robert Mylne (1734-1811) carried out much of the pioneer work on arch-bridge design, his first major work, Blackfriars Bridge, London,

being completed in 1769. (It was replaced by the present wrought-iron structure in 1869.) In this bridge Mylne incorporated elliptical arches, an innovation in Britain; inverted arches in the piers between the springings of the two adjacent arches bearing on them; and the multiple or crocket wedge support for the timber bridge centres, which enabled the centring to be lowered gradually and any weakness in the arch itself to be detected at an early stage.

John Rennie (1761-1821) is much better known, but may be regarded as a successor to Mylne in the field of bridge building. Born at Phantassie, near East Linton, some 20 miles from Edinburgh, Rennie grew up in contact with the crafts of millwrighting, blacksmithing, stonemasonry and carpentry and learnt much about them from one of his father's tenants, Andrew Meikle (1719-1811), the celebrated mechanical engineer and windmill improver. After an education at Edinburgh University, which brought him into contact with leading scientific minds, Rennie established himself as an engineer working on canals, docks, steam engines, land drainage schemes, roads and mills, as well as some notable bridges. His most famous masonry bridges were Waterloo Bridge, London, completed in 1817 and now replaced by a reinforced-concrete beam structure; and London Bridge, completed in 1831 as successor to the famous medieval bridge and now removed to Havasu City, Arizona. The foundations of both these bridges were on piles built within cofferdams. Rennie's Waterloo and London Bridges, and his other Thames bridge, at Southwark, have all now been replaced, but Kelso bridge over the River Tweed, his first major structure, still stands at the southern approach to the town (70/NT 727336). It has five elliptical arches, each of 72ft span, and was virtually a small-scale prototype for Waterloo Bridge. Rennie's bridge-building abilities, like those of Telford a few years later, stood him in good stead for his work on canals in which, besides innumerable humble occupation crossings, mostly built to a standard design, he was responsible for a number of aqueducts, including the spectacular structure across the River Lune at Lancaster (89/SD 484638). These will be considered in Chapter 14. His standard bridges may be seen in profusion along the Lancaster Canal and the Kennet & Avon Canal. Most have walls curved on plan, so acting as arches springing from the buttress piers at each end; and in addition the walls are battered, making the whole bridge immensely strong.

Before turning to iron bridges, in which Rennie had been involved at Southwark, a number of other surviving masonry structures are worth noting. In Chester, Grosvenor Bridge across the Dee (109/SJ 403656), designed by Thomas Harrison (1744-1829) and opened in 1832, has the widest masonry span in Britain—200ft, with a rise of 40ft. The complete arch has, in fact, a span of 230ft, as it extends into the abutments to carry the thrust more effectively down to piling foundations. Harrison also designed the elegant Skerton Bridge in Lancaster (89/SD 479623). Telford's masonry bridges never reached the standards of structural elegance of his graceful cast-iron bridges. His first major work, Montford Bridge (118/SJ 433153) of 1792, carrying the Holyhead road over the Severn west of Shrewsbury, is very much in the eighteenth-century classical tradition, but his next, Tongue-land Bridge (80/NX 693534) across the Dee near Kirkcudbright, with its single 112ft span, is of considerable technical interest. Here Telford first introduced hollow spandrels to lighten the load on the foundations, but, instead of piercing with tunnels as Smeaton and Edwards had done, he replaced the normal rubble fill with a series of parallel walls within the spandrels themselves. Pierced spandrel bridges may be seen at Pontypridd, Glamorgan (154/ST 074904), built in 1755 by William Edwards (1719-89), and Coldstream, Northumberland (64/NT 848402), designed by John Smeaton (1724-92) and completed in 1763. In the latter example the tunnels are covered at the ends with ornamental discs. Returning to Telford and his masonry bridges, Dean Bridge, Edinburgh (62/NT 243740), over the Waters of Leith, completed in 1832, is perhaps his finest surviving stone structure, while Over Bridge, Gloucester (143/SO 817196), is interesting for its ingenuity. The splaying of the 150ft span arch, in which the two faces of the bridge are in effect chamfered to form 'cow's horn voussoirs', is based on Perronet's Pont de Neuilly over the Seine. Over Bridge is likely to be demolished in the near future.

The completion in 1779 of the first metal bridge structure in the world, the Iron Bridge (Plate 67) over the River Severn near Coalbrookdale in Shropshire (118/SJ 673034), marked the beginning of the end of stone as the

67 The Iron Bridge, across the River Severn in Shropshire. Cast at the nearby Coalbrookdale Works in 1779, this was the first major civil engineering work in the world in which iron played a structural role





68 The Iron Bridge. Detail of arch showing dovetailing of radial members into ribs

major bridge-building material. The Iron Bridge derives all its structural principles from its stone predecessors and is, in effect a natural successor to the works of Edwards and Smeaton, who pioneered the reduction in self-weight of bridge structures. Like stone bridges, it has a compression arch, but close examination of the methods of construction reveals that techniques more appropriate to timber fabrication have been used in its assembly. The various components were designed to pass through one another and mortice or dovetail together (Plate 68), and are secured by wedges. No bolts or rivets were used. The bridge has a span of 100ft and the rise is 45ft. There are five main ribs of 12in by 6½in section and 70ft long, virtually hinged at the springing and at the crown. They were cast in open sand moulds at the Coalbrookdale works of Abraham Darby.

Credit for the design of what is perhaps the most important monument of the Industrial Revolution in Britain is usually accorded to Thomas Farnolls Pritchard (d 1777), a Shrewsbury architect, who certainly prepared drawings for a 120ft flat-arched iron bridge as early as October 1775. In



69 Restoration of the Iron Bridge. Excavation of the north abutment and insertion of reinforced concrete strengthening

association with the ironmasters John Wilkinson (1728–1808) and Abraham Darby III (1750–91), Pritchard discussed schemes for a bridge, but his death in 1777 left the project entirely in Darby's hands. Who was responsible for the design of the 1779 bridge as constructed remains, therefore, something of a mystery.

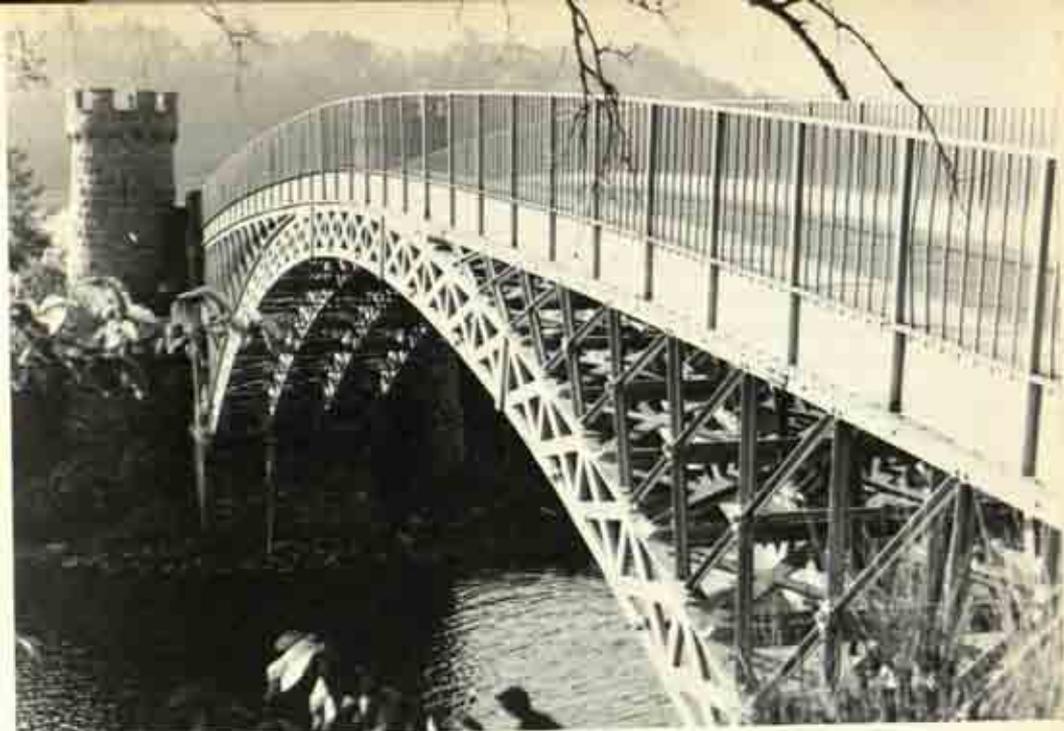
There is no doubt, however, that the Iron Bridge proved to be an inspiration to other civil engineers. Thomas Telford used iron for the bridge at Buildwas, a few miles upstream from Coalbrookdale. The previous masonry bridge had been swept away by a flood in 1795 and Telford replaced it with a single iron span of 130ft weighing 173 tons, in contrast to

the 378 tons of the first 1779 iron bridge. Buildwas Bridge (118/SJ 645044) survived until 1906, when it was replaced by the present steel structure.

Numerous designs for iron bridges were tried between 1795 and 1820. In 1796 a 236ft iron span was completed across the River Wear at Sunderland to the designs of Rowland Burdon, a local MP, who in the previous year had patented a system of construction involving separate openwork cast-iron voussoirs held together with wrought-iron straps instead of the ribs being cast complete, as at Ironbridge or Buildwas. The idea was not a complete success and two subsequent bridges built at Staines, 1802, and Yarm, 1805, collapsed soon after completion. Sunderland Bridge survived for half a century before requiring substantial modification and eventual replacement. Two bridges incorporating Burdon's patent still survive—at Spanish Town, Jamaica, 1801, and Newport Pagnell, Buckinghamshire, where Tickford Bridge (146/SP 877437) across the River Ouzel, completed in 1810, still carries the heavy traffic of the A50.

Open-frame voussoirs fell into disrepute as a result of these and other collapses, and Coalport Bridge of 1818 (119/SJ 702021) is an example of the return to ribs cast in complete sections. There are few eighteenth-century survivors of this type of construction, but those that do exist usually have characteristic features suggesting that the founders had some influence in the design. Thus the spans at Cound, Shropshire (118/SJ 556053), dated 1797 and presumably supplied to Telford, those at Bath over the Kennet & Avon Canal (156/ST 758654), one of two supplied to Rennie, and those at Tewkesbury (143/SO 893330), of unknown date, all have a diminishing circle motif in the outer ribs of the arches.

By 1815 really large iron bridges were being built, notably by Telford and Rennie. At Bettws-y-Coed (107/SH 799558) Telford's graceful arch provides a splendid example of the ironfounders' art. The outside ribs carry the legend, in finely proportioned openwork lettering, THIS ARCH WAS CONSTRUCTED IN THE SAME YEAR THE BATTLE OF WATERLOO WAS FOUGHT, across the full width of the arch. In the spandrels are enormous heraldic flowers—roses, thistles, shamrocks and leeks—a degree of decoration seldom seen in Telford's work. The arch was cast by William Hazledine at Plas Kynaston and erected by William Stuttle. Both their names are cast into the base of the balustrading. The Waterloo Bridge is surprisingly little known, perhaps because a good view of the arch involves scrambling down



70 Thomas Telford's cast-iron bridge of 1814 across the River Spey at Craigellachie, Banff

71 Cast-iron plaque Craigellachie Bridge: "Cast at Plas Kynaston, Ruabon, Denbighshire, 1814"



the river bank almost to water level. The effort is well worthwhile, however, and an examination of the underside of the arch reveals the sympathetic way in which it has been strengthened and widened without destroying its original character. In Scotland Telford's magnificently sited bridge at Craigellachie (29/NJ 285452), with its ornamental castellated towers and 152ft arch of trussed iron ribs (Plates 70 and 71), has also been carefully renovated in recent years, using new components and epoxy resin adhesives. Similar large, although less spectacular, Telford bridges are Holt Fleet Bridge, Ombersley, Worcestershire (130/SO 824634); Mythe Bridge, Tewkesbury (143/SO 888337); and Galton Bridge, Smethwick (131/SP 015894). Unfortunately John Rennie's masterpiece in cast iron, the 240ft span Southwark Bridge over the Thames, built between 1814 and 1819, no longer survives. It was replaced by the present steel-arched bridge in 1922.

The need for spans larger than were feasible even with cast-iron bridges became a real one by the 1820s, when the new roads and greatly increased traffic created a demand for shorter and more direct routes. The suspension bridge satisfied this need, and wrought iron, becoming readily available as a result of Henry Cort's pioneer work in the 1780s on the development of the puddling process, meant that for the first time material existed from which suitable chains could be made. A number of suspension bridges were built in

72 Date plaque, Prince's Bridge, Salford, 1905



south Scotland. The greatest, with a span of 300ft, was completed in 1820 by Captain Samuel (later Sir Samuel) Brown, RN (1776-1852), and crossed the Tweed at Kelso. (It has since been demolished.) Brown had introduced the chain cable to the Royal Navy and in 1817 took out a patent for wrought-iron links which he incorporated in the Union Chain Bridge across the Tweed near Berwick (64/NT 934511). Completed in 1820, this earliest surviving suspension bridge has a span of 361ft and an 18ft deck hung from twelve wrought-iron chains. Major repairs have been undertaken on two occasions, the first in 1871-2 by the Berwick and Norham and Islandshire Turnpike Trustees and the second in 1902-3 by the Tweed Bridge Trustees, who now care for the bridge. A steel cable has been added on each side above the chains to help them support the platform. The tollhouse on the English side has been demolished (the bridge was made free in 1883) but that on the Scottish bank, which once belonged to the Berwickshire Turnpike Trust, still stands.

In 1819 the Act was passed for building Menai Bridge (107/SH 556714) to carry the Holyhead road from Anglesey to the mainland of Wales. Its designer, Thomas Telford, initially favoured a cast-iron arch construction similar to a scheme put forward in 1801 by Rennie, but Admiralty insistence on unobstructed navigation through the Straits resulted in his adopting the suspension principle, and on a scale far exceeding anything previously built. Work began on the piers in 1819 and on the manufacture of the iron chains in 1821. The links, each a little over 9ft long, were wrought at Upton Forge (118/SJ 560113) in Shropshire, sent to Hazledine's Coleham works in Shrewsbury for testing on a specially designed tensile machine and forwarded thence by canal to Chester and sea to Menai.

The Menai Bridge must be one of the most carefully built structures in the world. Telford, acutely conscious of the step he was taking into the unknown, tested each link of the sixteen suspension chains 100 per cent in excess of the calculated working load and then tested each complete chain in tension before final erection. The stones of the towers are dowelled together with iron pegs and the chains which they support run back 60ft into tunnels blasted in the rock. The main span is of 579ft, with a headroom of 100ft to satisfy Admiralty navigation requirements. Each of the main piers is 153ft high and is approached by a masonry viaduct of three arches on the Caernarvon side and four on the Anglesey side of the straits. Com-

pleted in 1826, like its smaller neighbour at Conway (107/SH 786777) on the Chester road, Menai Bridge formed the last link in the road from Holyhead to London. Despite Telford's care in design and construction, various components have had to be replaced. In 1839 the unstiffened timber deck was wrecked in a storm; a heavier timber deck lasted until 1893, when Sir Benjamin Baker reconstructed it in steel; and this in turn was replaced in 1940, when the tolls were also abolished and the chains replaced in high-tensile steel.

The success of Menai encouraged others to build suspension bridges. William Tierney Clark (1783-1852) designed the old Hammersmith Bridge, built in 1827 and replaced 60 years later, and a beautiful 271ft span suspension bridge at Marlow (159/SU 852862), completed in 1832 and still standing. So is Clark's major work, the 666ft span suspension bridge at Budapest. Victoria Bridge, Bath (156/ST 741650), across the River Avon, completed in 1836 to the designs of J. Dredge, is of unusual construction, as the suspension rods from the catenary chains are inclined towards the piers instead of being vertical, a device intended to increase structural stiffness. Undoubtedly the most spectacular of the great nineteenth-century suspension bridges, however, is the epic Clifton Bridge (156/ST 564731), designed by I. K. Brunel in the late 1820s and finally completed in modified form in 1864. The first moves to bridge the Avon gorge at Clifton date from 1753, when William Vick, a Bristol wine merchant, bequeathed £1,000 to the Society of Merchant Venturers with the instruction that it should be allowed to accumulate to £10,000 when, it was hoped, a bridge could be built. By 1829 the amount had increased to £8,000, and a competition was held to seek a suitable design. Numerous schemes were submitted, including an improbable gothic structure by Telford, who was one of the judges, and several by Brunel. A modified Brunel design was finally selected, work began in June 1831, the foundation stone was laid in 1836 and in 1840, when the piers were substantially complete, money ran out. The chains were sold in 1853 to the South Devon Railway for use on Brunel's other major bridge, the Royal Albert Bridge over the Tamar at Saltash (187/SX 435587). In 1859, when Brunel died, Clifton Bridge, the starting point of his independent engineering career, was no further advanced, but the prosperity of the 1860s coupled with sorrow at the loss of a great engineer, at the relatively early age of 53, revived interest in the scheme. A new company was formed

by some of the principal members of the Institution of Civil Engineers and, utilising the chains from the recently demolished Hungerford suspension bridge across the Thames, also designed by Brunel, they opened Clifton in December 1864. With little modification it stands today, linking Gloucestershire and Somerset 245ft above the Avon. The span is 702ft 3in and the total weight of ironwork 1,500 tons. Incidentally, the piers of Brunel's Hungerford Bridge still help to support today's rail and foot bridge between Waterloo and Charing Cross.

The beam type of bridge had little application on roads in the nineteenth century, although it was extensively used on railways. Recently, however, beam bridges in steel and prestressed concrete have appeared in profusion on motorways and other modern roadworks. The early development of reinforced concrete was pursued largely in France by engineers such as François Coignet (1814-88) and his son Edmond (1850-1915), and François Hennebique (1842-1921). The structural use of concrete poured *in situ* was adopted only slowly in England and no major bridge in the new material appeared until after the World War I. A very early example still survives across the River Axe at Seaton in Devon (177/SY 253900). It was completed in 1877 and has a central span of 50ft. On a much larger scale the Royal Tweed Bridge at Berwick (64/NT 995528), opened in 1928, exemplifies the ponderous designs of the interwar years before prestressing brought to concrete a supreme elegance and daring worthy of the great nineteenth-century pioneers.

Before leaving road bridges altogether, a curious and somewhat bizarre answer to the problems of spanning large rivers and at the same time maintaining headroom for navigation is worthy of brief mention. The transporter bridge, in effect an aerial ferry, had a brief period of popularity at the end of the nineteenth century and beginning of the twentieth as a solution to the problem in flat country or urban areas of low-level approach roads making a fixed bridge impractical. By supporting a girder at high level between two towers, vehicles could be carried across the gap on a platform suspended by cables from a trolley running on rails above. The idea was originally proposed by a British engineer in the 1870s, but was first put into practice by the Frenchman F. Arnodin in 1893 at Portugalete, near Bilbao, in Spain. Four transporter bridges were built in Britain and three of these are still extant. The largest, in fact the largest in the world, crossed

the Mersey between Widnes and Runcorn. It was of the suspension type with a span of 1,000ft and was in use from 1905 until 1961, when the present high-level steel-arch structure replaced it.

In 1906 a smaller transporter bridge, also of suspension type, was completed across the Usk at Newport (155/ST 318863). Of 645ft span, it is still in regular use. The Middlesbrough transporter bridge (85/NZ 500213) is of a completely different form of construction, as its overhead deck is cantilevered, the outer ends being anchored with massive vertical cables. Opened in 1911, it has a span of 570ft and accommodation for 600 passengers and up to ten vehicles on the electrically propelled carriage. Much less known than these two is the privately owned transporter bridge across the River Mersey at Warrington (100/SJ 597877), connecting the two halves of the extensive soap and chemical works of Messrs Joseph Crosfield & Son Ltd. Compared with Newport and Middlesbrough, it is small, with a semi-cantilevered span of only 187ft. Built in 1916, and out of regular use since 1964, it was the last of the total of sixteen transporter bridges to be constructed.

## 14 Rivers and Canals

FROM the end of the Roman occupation until the mid-eighteenth century rivers were the main arteries of communication in Britain. They formed natural highways and were of paramount importance in influencing the settlement of people, the location of towns and the development of trade and commerce. Although susceptible to drought and flooding, rivers offered much greater reliability than roads, particularly where these crossed clay country. The Romans not only supplemented their comprehensive road system by river transport but sought to improve the latter with embankments. In the case of the Trent and the Witham they even cut a canal—the Fossdyke (Torksey Lock, 104/SK 837781 to Brayford Pool, Lincoln, 113/SK 970713)—in order to establish direct communication between them. A thousand years elapsed before any further improvements were carried out, although legislative procedures established rights of navigation over many rivers. There were numerous obstructions, however, shallows in dry weather, fishgarths for catching fish, and the dams and weirs of millowners being the major difficulties. In the sixteenth century eight Acts were passed dealing with rivers and the improvement of navigation, including one in 1571 to bring the River Lea to the north of London by making an artificial cut. By 1750, on the eve of the great era of canal building, Britain had 1,000 odd miles of navigable river, some of which, such as the Aire & Calder from 1699, had only been rendered navigable by the construction of cuts and pound locks. The early river engineers, such as Andrew Yarranton (1619–84?), had accumulated considerable experience of the problems of establishing navigations and their work, together with that of the fen drainers, provided the essential technological foundation for the canal engineers of later years.

A prominent feature of many improved rivers was the flashlock, which had its origins in the Middle Ages, often as a compromise between navigation and milling interests. Where water was impounded for a mill, a device was needed to pass boats through the weirs; and in between mills also, weirs

were often necessary to maintain adequate depths of water for navigation. If a section of the weir was made removable, usually by the insertion of a gate, boats could pass through. These flashlocks, when opened, resulted in a powerful flush of water running downstream and boats simply 'shooting the rapids'. Those going upstream had to wait until the main force of water had subsided, when they were winched through the lock against the flow. The lock would then be closed and the water level allowed to build up for the next vessel. In a dry summer this might take several days and could, in extreme conditions, prevent navigation altogether. In many cases these flashlocks were replaced by pound locks, similar to those found on canals today, for flashlocks were highly dangerous and wasteful of time and water. A variation of the flashlock, usually known as a staunch, operated on a similar principle but was normally kept open to the river flow. Staunches were installed where flashlocks or pound locks were not always desirable, particularly on rivers with numerous mills, as impounded water would tend to back up the tailraces of waterwheels and reduce their efficiency. Also if a river was crossed by a ford, as, for example, at Tempsford on the Great Ouse (147/TL 161542), it was essential that the river level was not increased at the crossing point. The method of operation of staunches was even more tedious than that of flashlocks, a man usually preceding the boat to close the gates and allow sufficient water to build up.

Most flashlocks and staunches took the form of vertically hinged gates; these were rarely single but generally a pair of mitre gates like those on any canal lock. The angle between them was commonly 90 degrees, in contrast to the 120 or 130 degrees of canal and more modern river locks. In East Anglia guillotine staunches were sometimes used, and then the gate was raised vertically like a sash window and the boats passed underneath. A third and very simple type consisted of planks let into vertical slots in masonry walls, and was similar to the stop-planks commonly used on canals to isolate sections for repair. Perhaps the oldest form, however, was the beam and paddle weir, in which a beam was swung horizontally over a wooden cill across the bed of the lock. When closed, vertical boards or 'rimers' were put between beam and cill, and against these were set square planks with handles to hold back the water.

Most of the remaining flashlocks are decayed and ruinous, but a fine and nearly complete beam and paddle type can be seen on a small tributary of

the Thames just below Eynsham Lock (158/SP 446089), Oxfordshire. Although traffic on this  $\frac{1}{2}$  mile navigation to Eynsham Wharf ceased in 1925, the beam still survives, bolted to the stop-post and supporting a foot-bridge. A substantially complete staunch on the Great Ouse may be seen at Castle Mills (147/TL 094509), with brickwork, c1840, intact and the decrepit remains of gates. Its purpose was to deepen the shallows below Castle Mills Lock, 300yd above. Tuddenham Mill Stream, a tributary of the Lark, which in turn flows into the Great Ouse, also has a well preserved gate staunch (135/TL 732729), with mitre gates, each with a single paddle (or sluice). There is a guillotine staunch, complete except for the spoked wheel used to lift the gate, at Bottisham Lode (135/TL 516651), which probably dates from the 1820s and was in use until navigation on this obscure tributary of the Cam ceased about 1900.

Like the navigable rivers, canals were chiefly used to move heavy bulky goods for which roads were unsuitable. Britain was slow to begin building canals, but, once started, quick to extend a network over much of England, with separate systems in Wales and Scotland. By 1850 the 1,000 miles of river navigation that had existed in 1750 had been expanded to a total of 4,250 miles as a result of canal building. The first canals were dug to connect or supplement existing river navigations or to link otherwise isolated agricultural or industrial communities with navigable water. The Newry Canal in Ireland, completed in 1742, was the first 'deadwater navigation' in the British Isles. It was followed in England by the Sankey Brook Navigation from the St Helens coalfield in south Lancashire to the River Mersey. Financed by Liverpool merchants, salt refiners and the town corporation, it was substantially complete by 1757 and can undoubtedly claim the distinction of being England's first canal. Its economic success was immediate and high dividends were paid. Soon after came the Bridgewater Canal, built by John Gilbert and James Brindley (1716-72) to connect the Duke of Bridgewater's collieries at Worsley with Manchester. On its completion in 1761, the price of coal in Manchester dropped by half. The canal revolution had begun.

James Brindley, the 'father of English canals', was born in Derbyshire and began work as an apprentice wheelwright and millwright at Sutton near Macclesfield. By 1742, at the age of twenty-six, he had his own business in Leek, where Brindley Mill (110/SJ 977570) survives as a memorial to his early

career. His considerable abilities became well known in Staffordshire and brought him for the first time into contact with a canal scheme, to connect the Trent and Mersey rivers, for which he was asked to carry out a survey. The Trent and Mersey project was to remain a dream for some years, but it was his work in connection with it that brought Brindley to the notice of the Duke of Bridgewater and gained him his first definite commission for a canal. The 'Bridgewater', and the masonry aqueduct which Brindley designed to take his canal over the River Irwell, fired the imagination of the age. The three great arches carried the canal 38ft above the level of the river, enabling flats (sailing barges) to pass beneath. Completed in July 1761, it became a local wonder—'Vessels o'er vessels, water under water, *Bridgewater* triumphs — art has conquered nature.' It survived until 1893, when construction of the Manchester Ship Canal, which was built largely on the site of the Mersey & Irwell Navigation, necessitated its demolition. The abutments, however, can still be seen (101/SJ 767977), and give an indication of the massive construction. The replacement is a still more remarkable structure, a unique swinging aqueduct designed by Sir E. Leader Williams, engineer of the Ship Canal. A pivoted steel tank 235ft long, 18ft wide and 6ft deep provides a crossing for the Bridgewater 26ft above the Manchester Ship Canal. When passage of the ship canal is required, the tank is swung by hydraulic power on its central pier, the total weight of the span and its load of water being 1,450 tons. The first barge passed over Barton swing aqueduct on 21 August 1893, and Brindley's pioneer structure was then demolished.

At the west end of the Bridgewater Canal, Worsley Mine was an integral part of the project, and the line of the canal was continued into the vertical rock face at Worsley Delph (101/SD 748005) to form the basis of an underground network of waterways on which the coal was brought out. Underground channels known as soughs were in use before 1750 for draining coal workings north of Worsley, and it seems probable that these were adapted to give direct access by boat between the coalfaces and the main line canal. James Brindley was closely involved with the underground scheme in its early years, as was John Gilbert, the Duke's superintendent engineer, agent and surveyor, who was probably responsible for extending it in the years down to his death in 1795. The network grew continually until about 1840, when some 46 miles of underground waterways extended under Walkden and Farnworth. To tap deeper seams, separate systems were also

dug at levels below the main line and connected to it by shafts; the deepest was 83ft below the level of the entrance tunnels. Further north a higher level system was connected to the main level by a 150yd underground inclined plane on which the boats were worked on wheeled cradles running on rails. At the Delph can be seen the two entrances to this system, cut about 30ft apart in the rock face. Note also the hand-crane with a wooden gib used for inserting the stop-planks (101/SD 747004) and the drydocks on the Bridgewater Canal. Examples of the long narrow boats, nicknamed 'starvationers', which were used in the tunnels can be seen in the North Western Museum of Science & Technology, 97 Grosvenor Street, Manchester.

Following the success of the Bridgewater the number of canals multiplied rapidly before 1773 and after 1787, the movement reaching a crescendo in the 'mania' of 1789-93. Three main types were developed—wide canals for some main lines, particularly those associated with rivers; narrow canals, with 7ft locks, for hilly inland routes that frequently suffered from poor water supplies; and tub-boat canals, where gradients were particularly steep. Wide canals were built mainly in Lancashire and Cheshire, in the East Midlands, and in the south wherever connection with tidal water was important. The gauge was usually about 14ft. The pattern of the narrow waterways was set by Brindley's Staffordshire & Worcestershire and Trent & Mersey canals, completed in 1772 and 1777 respectively. The need to economise on constructional costs where large numbers of locks and tunnels were needed resulted in major concentrations of narrow canals round Birmingham and also in South Wales. Tub-boat canals were built in Shropshire and the South West. Within these groups there were numerous minor variations, but, generally speaking, a *narrow boat* 70ft by 7ft could travel anywhere south of the Rivers Trent and Mersey, except on the tub-boat canals, and a *barge* 58ft by 13ft 6in anywhere north of that line. Larger barges worked on the river navigations.

The lack of uniformity in canal size and the total absence of planning prevented the canal network from ever being an integrated system. The geography of Britain meant heavily locked waterways, with consequent problems of water supply for summit levels; and many areas, notably much of Scotland, the far north of England and the south-west peninsula, were quite unsuited to artificial waterways. The web of canals was densest in the industrial Midlands where Birmingham, first entered by canal in 1772,

became a focus of waterways. The estuaries of the Thames, Severn, Humber and Mersey were soon connected, the Pennines traversed, and London linked with the Midlands and North. In the south of England more than 430 miles of canal were dug, but with one or two exceptions few navigations paid dividends higher than 5 per cent. Of little industrial importance, the largely agricultural south did not have the traffic potential to make profits. By contrast such waterways as the Aire & Calder network, the Loughborough Navigation in Leicestershire and the Trent & Mersey Canal carried huge quantities of raw materials and manufactured goods. In 1824 the last two were paying dividends of 197 per cent and 75 per cent respectively. In South Wales too a series of short and generally unconnected canals provided for the thriving coal and iron trade of the valleys, stimulating the growth of coastal centres such as Cardiff and Newport, and supplying coking coal and iron ore to great ironworks complexes such as those at Merthyr Tydfil. The terrain in much of South Wales, and parts of the North East around the valleys of the Tyne and Wear, was totally unsuited to canal construction, however, and in these areas parallel development of horse tramroads began, to feed canals or rivers.

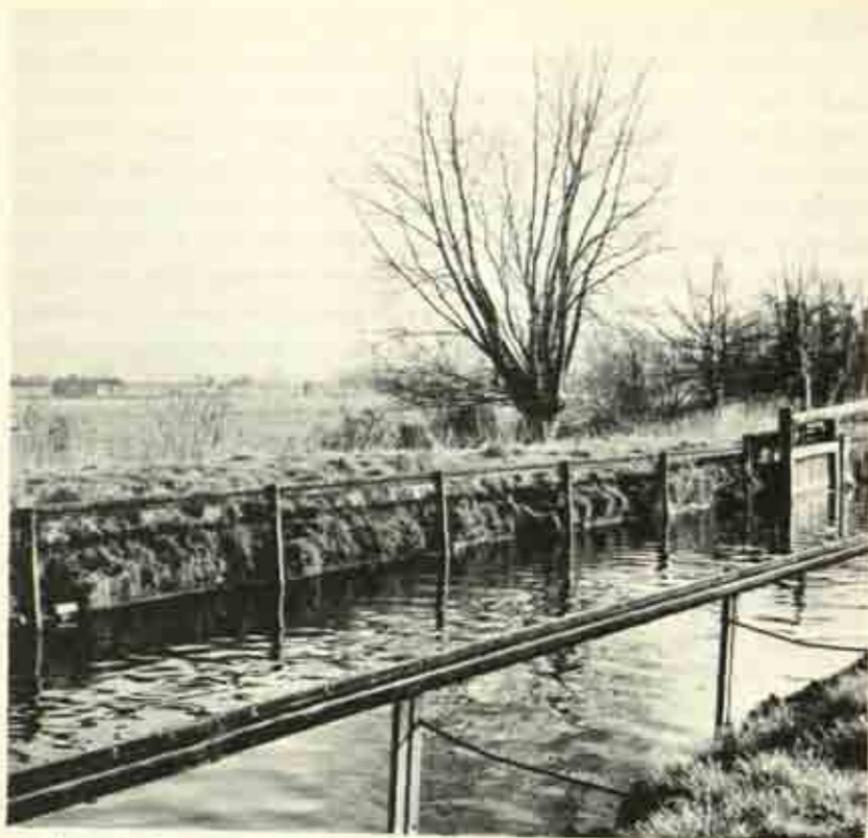
As already mentioned, the early canals were built as cheaply as possible. A typical Brindley canal, such as the Staffordshire & Worcestershire, follows the contours with hardly an embankment or cutting of any size upon it. The extra length resulting from their winding courses mattered little when boatmen's wages were low and effective competition non-existent. The threat of road and railway competition led to an increase in the efficiency and enterprise of waterways and to efforts at improvement. Harecastle Tunnel (110/SJ 837342 to 849517) on the Trent & Mersey canal was doubled in 1827, the new tunnel (16ft high and 14ft wide) taking only 3 years to build in contrast to the 11 years taken by the original bore (12ft high by 9ft 3in wide) of the 1770s. Engineering techniques had improved. In other cases routes were shortened, a notable example of the straightening of a contour canal being the Oxford, which was reduced from 91 to 77½ miles between 1829 and 1834. New canals themselves were made as straight as possible, even at the expense of considerable civil engineering work to maintain the level. Thus Telford's Birmingham & Liverpool Junction (now the Shropshire Union main line), completed in 1835, has long stretches of embankment and cutting, including the 2 mile long Tyrley Cutting (119/SJ 693315),

the deepest in the country.

The obstacles facing canal engineers were overcome in a variety of ways. Locks were the normal method of climbing hills, tunnels and cuttings for going through them and aqueducts for crossing rivers or valleys. The river improvers with their flashlocks and staunches anticipated the common pound lock used on most canals in England. A century after its first known use in continental Europe, in 1373, the pound lock was in use on river navigations in Britain. It consisted of lifting or swinging gates enclosing a 'pound' of water of sufficient length to accommodate a boat. On the River Wey, made navigable from the Thames to Guildford, Surrey, under an Act of 1651, pound locks with turf sides, now reinforced, have survived in substantially original form, as at Papercourt (170/TQ 034568) and Walsham Gates (170/TQ 050578). Sheffield Lock on the Kennet Navigation, Berkshire (158/SU 649706), is also turf-sided (Plate 73).

On canals the lock evolved with a brick or masonry pound, generally rectangular in plan and of the minimum dimensions capable of handling the largest type of craft using the canal. Thus the smallest amount of water was consumed. In the Midlands a typical 'narrow' lock has a chamber 7ft wide and about 76ft long designed for boats of 6ft 10in beam and up to 72ft in length. The extra length of the chamber allows for the inward-opening bottom gates. The mode of operation is simple. A boat working down requires a full lock to enter. When the boat is in the chamber and the gates are closed, sluices, usually known in this context as paddles, at the lower end or tail of the lock are opened and as soon as the levels inside and outside are the same, the gates can be opened and the boat passes through. In locking up the procedure is followed in reverse.

Lock gates are generally of timber, oak being most commonly used, although on the Montgomeryshire and Ellesmere canals cast-iron gates were used in the early nineteenth century. A pair from the former canal can be seen at the Waterways Museum, Stoke Bruerne, Northamptonshire (146/SP 743500). The gates at the tail of the lock are the heavier because they extend the full depth of the lock, whereas those at the upper end or head need only be the depth of the upper pound of the canal. Double gates are generally used on river navigations and barge canals, but in narrow locks single top gates and double bottom gates are commonly found. Both upper and lower gates bed against a cill at the bottom of the chamber, the upper cill being



73 The turf-sided Sheffield Lock on the Kennet Navigation, Berkshire

exposed when the lock is empty. Cills are often made of timber, although concrete has been increasingly used in recent years. Gates have a vertical timber at the hinge end known as the heel post which fits into a hollow quoin in the masonry wall of the lock. Only a light iron strap is needed to maintain the gate in place as water pressure holds the heel post tightly into the quoin when the gate is closed. The outer end of the gate also has a vertical post called a breast or mitre post, which fits a rebate in the opposite wall of the lock or, in the case of double gates, the equivalent post of the partner gate. A gate is operated by a balance beam, which, as the name suggests,

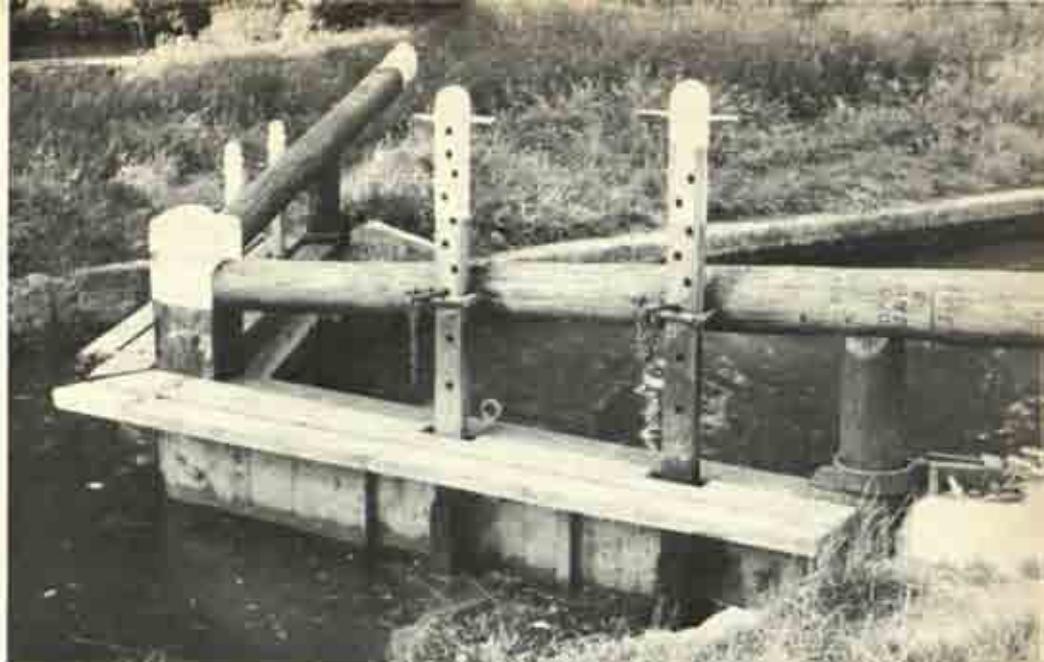
74 Guillotine lock gate on the Shrewsbury Canal



provides the counterweight to the gate itself. Traditionally this beam was of timber but in many modern replacement gates rolled steel joists with concrete balance weights have been used. The guillotine gate (Plate 74) is not common on British canals, but examples can be found on the old Shropshire Canal section of the Shropshire Union north of Hadley (119/SJ 672133) and at King's Norton stop-lock at the junction of the Stratford-upon-Avon Canal with the Worcester & Birmingham (131/SP 053795). Modern guillotine gates can be seen on the Rivers Nene and Great Ouse, where their use more easily enables flood water to run through the lock.

Locks are filled and emptied by sluices, generally known as paddles but also called slackers in the Fens and cloughs in the North of England. Gate paddles fitted on the lock gates themselves are found at head and tail of most river navigation locks, and on the tail gates and occasionally head gates of canal locks. Ground paddles are mounted in the wall of the lock and admit water through culverts; they are generally used in combination with gate paddles at the head of a lock. Ground paddles used for drawing off water from a lock are rare features but can be seen on some of the wide locks on the stretch of the Grand Union between Napton and Birmingham. The paddle itself usually consists of a slab of elm that slides vertically in a frame across the sluice aperture. A wide variety of mechanisms for lifting or drawing paddles can be found, the most common being the rack and pinion arrangement incorporating a pawl to hold the paddle in the drawn position. Worm-and-nut gearing is used on the ground paddles of the Leeds & Liverpool Canal, and on the same navigation pivoted gate paddles can be found, a very rare feature. On the River Wey at Worsfold Gates, near Send, Surrey (170/TQ 016557), some paddles still operate in their most primitive form; they are lifted by hand and held in position by pegs through holes in the handles (Plate 75). Nearby are the Navigation's workshops, which are still in use. Nowadays, of course, many locks are mechanised, as on the Caledonian and Aire & Calder Canals and the Rivers Trent and Thames.

Groups or 'flights' of locks are commonly found on canals where great differences in level occur in a relatively short distance. The largest flight in Britain is at Tardebigge on the Worcester & Birmingham Canal, where thirty narrow locks raise the canal 217ft in about 2 miles. The summit lock at Tardebigge is, in fact, the deepest narrow lock in the country, with a fall



75 Peg-and-hole gate paddles at Worsfold Lock, on the Wey Navigation, Send, Surrey

of 14ft; this is exceptional and the average is 6–8ft. A flight almost equal to Tardebigge can be seen at Devizes, where the Kennet & Avon Canal climbs out of the Vale of Pewsey through twenty-nine wide locks. This flight is far more spectacular, however, as the locks are very close together and most of them in a straight line. At Combe Hay (166/ST 748604) on the Somersetshire Coal Canal one can see most of the locks of a flight of twenty-two completed in 1805 after the failure of a novel boat lift. The canal was closed in the 1890s, and later part of its bed was utilised for the Limpley Stoke to Hallatrow branch of the Great Western Railway, opened in 1910.

A variation on the simple flight of locks is the staircase, where the top gate of one lock forms the bottom gate of the one above. A notable example is to be seen at Foxton (133/SP 692895) where the Leicester line of the Grand Union Canal descends by means of two staircases, each of five locks. To economise in the use of water—always important to the canal operator—side-ponds were frequently built in association with staircases of locks, and these are used at Foxton. The side-pond consists of a chamber beside the locks at a level halfway between the upper and lower pounds and com-

municating with the pounds by culverts controlled by ground paddles (side-pond paddles). When a boat enters the full pound and the gates are closed, the side-pond paddle is opened first, until the levels equate and slightly less than half the water is in the side-pond. The side-pond paddle is then closed and the remainder of the water in the lock released into the lower pound in the normal way. The saving occurs when a boat locking up enters the empty lock, which can then be almost half-filled with water from the side-pond. Thus only the remaining half has to be drawn from the upper pond. A well known staircase of wide locks is Bingley 'Five Rise' (96/SE 108400) on the Leeds & Liverpool Canal (Plate 76). Here there are no side-ponds and water passes direct from chamber to chamber. The largest staircase in Britain, of eight locks, is at Banavie (35/NN 147770) on the Caledonian Canal.

A curious and unique flight of three locks is to be seen at Bratch (130/SO 867938) on the Staffordshire & Worcestershire Canal, where at first sight the locks appear to be arranged in a staircase. However, each lock has its own gates, the top gate of one lock being only a few feet from the lower gates of the lock above. Further south at Botterham (130/SO 860914) on 76 Rack and pinion sliding gate paddles, Bingley 'Five Rise' Locks, Leeds & Liverpool Canal



the same canal is a double lock or rise of normal type with a common gate between the two chambers, while to the north lies Compton top lock (130/SO 884989), said to be the first lock built by Brindley. It is interesting to speculate as to whether Brindley devised the principle of the staircase immediately after building the Bratch locks or whether he was already aware of continental examples, such as the staircase at Béziers on the Canal du Midi in France. Other locks of interest include the sectional cast-iron lock chambers at Beeston (109/SJ 554599) in Cheshire, devised by Telford to overcome the problems of soft sand (Plate 77), and Northgate Locks, Chester (109/SJ 403666), which are partly cut in solid rock. On the Staffordshire & Worcestershire Canal circular weirs instead of the normal straight cill type are used for the culverts that convey surplus water from the head to the tail of some of the locks.

Besides problems of water supply, long flights of locks imposed considerable delays to traffic, particularly where this was heavy. Thus from as early as the 1780s canal engineers sought means of replacing locks with other mechanisms such as inclined planes, lifts, and a variety of patent balance-lock and caisson devices. In Britain no inclined planes remain in use, but their overgrown alignments, often almost completely obscured by trees and undergrowth, can still be found here and there. There were twenty or so in

77 Cast-iron lock at Beeston, Cheshire, built by Telford to withstand the pressures of shifting sand



south-west England alone, notably on the Bude Canal and the Torrington Canal in north Devon, where remains of Ridd incline (163/SS 476217) can still be traced. On most of these the boats themselves—usually tub boats about 20ft long—were hauled up the inclines in cradles or water-filled caissons running on rails. Perhaps the most spectacular and well preserved canal incline, which was also used for tub boats, is that at Coalport in Shropshire (119/SJ 695028). There was a vertical fall of 207ft between the upper line of the canal and the point at the foot of the Severn Gorge where goods were transhipped from the tub boats into barges on the river. This incline fell into disuse about 1900, but its alignment has been cleared by the Ironbridge Gorge Museum Trust, which hopes eventually to have it operating again. The incline installed at Foxton, Leicestershire (133/SP 692895), in 1900 with the object of superseding the time-consuming staircase of locks is less easy to trace. The incline was of the counterbalanced type, with movable tanks or caissons on wheels into which the narrow boats were floated. A steam engine at the top provided the power, but trouble was experienced with subsidence of the rails, and the volume of traffic did not justify the expense of keeping a boiler constantly in steam with staff in attendance. The incline had ceased to be used regularly by 1910 and the machinery was sold for scrap in 1928. Today the original locks are still in active use, but the unfortunate incline is rapidly disappearing into a jungle of brambles.

The only canal lift still in use (Plate 78) in Britain is that at Anderton (101/SJ 647753), near Northwich. It allows boats to pass between the Trent & Mersey Canal and the River Weaver Navigation some 50ft below. A proposal for a lift had been put forward as early as 1865 by E. Leader Williams, engineer to the Weaver Navigation, with the idea of facilitating the interchange of traffic between the two waterways, but not until 1872 were the necessary Acts passed and Emmerson & Co given the lift contract. The design was by Edwin Clark of Clark, Standfield & Clark, consulting engineers of Westminster. As completed in 1875, the Anderton lift had two wrought-iron caissons 75ft by 15½ft by 5ft rising and falling a distance of 50ft 4in within a substantial tubular iron framework. Each caisson could take two narrow boats or one barge and weighed 240 tons with its water. The caissons were supported on 3ft diameter hydraulic rams, the two rams being connected by a 5in pipe. Removing 6in of water, weighing some 15 tons, from the lower caisson made the heavier upper caisson descend,



78 Anderton boat lift, Cheshire, connecting the Weaver Navigation with the Trent & Mersey Canal

and water passed through the transfer pipe to the other ram caused the second caisson to rise. The final lift of 4ft was achieved by closing the transfer pipe and connecting the upper press to a steam-powered hydraulic pump and accumulator. Although a press burst in 1882, the Anderton design was a good one and formed the basis for other lifts in France and Belgium. In 1903 electricity replaced steam power for the hydraulic pumps and in 1908 further substantial modifications dispensed with hydraulic operation altogether in order to simplify working and increase capacity. As rebuilt, the lift's caissons are counterbalanced by cast-iron weights and can be operated independently. Power is provided by an electric motor driving through gears. In 1913 the lift transferred a record 226,000 tons of traffic, more than would have been possible before reconstruction. Today it is still in regular use, mainly by pleasure boats, and a 'voyage' in it is a fascinating if slightly unnerving

experience. One may make an excellent trip on a hire boat such as the *Lapwing* from Weston Docks, Runcorn (109/SJ 503830), up through the large 220ft x 41½ft locks of the Weaver to Anderton and up the lift, and then along the Trent & Mersey Canal through three tortuously narrow tunnels to the delightful little canal hamlet of Preston Brook. Here, at the junction of the Trent & Mersey and Bridgewater Canals (109/SJ 568806) one finds canal cottages, a large warehouse now used as a club, and a small roofed drydock.

On many canals there was no alternative to a tunnel when it came to cutting through hilly country. Canal tunnels are usually, although by no means always, on the summit level, crossing the watershed between one side of the navigation and the other. The first were on Brindley's Trent & Mersey Canal at Preston Brook (1,239yd, 109/SJ 570799), Saltersford (424yd, 101/SJ 624753), Barnton (572yd, 101/SJ 630749), and Harecastle. The latter, with its 2,880yd bore, carried the summit level under Harecastle Hill, the watershed between the valley of the Trent and the Cheshire plain. The original tunnel at Harecastle, like others on the canal, had a very small bore—only 9ft 3in wide and 12ft high (110/SJ 837542). Boats had to be legged through, the 'leggers' lying on narrow boards sprung out from either side of the boat and walking on the sides of the tunnel to push it through. In 1827 a new tunnel, parallel with the old, was completed to designs of Thomas Telford. It was of large section and had a towpath, but this has now been demolished. For some 90 years both tunnels were worked on a one-way system, but in 1918 colliery subsidence necessitated closure of the older bore.

Of even smaller section than the old Harecastle tunnel is Standedge tunnel (102/SE 006079 to 040120) on the Huddersfield Narrow Canal, which in places is only 8ft 6in high and 7ft 6in wide. Standedge, completed in 1811, is the longest canal tunnel in Britain (5,698yd) and on the highest summit above sea level. The 4½ mile level through the Pennines between Diggie and Marsden is 645ft above Ordnance datum. Although the canal was abandoned in 1944, the tunnel is still navigable. A through passage in a properly organised party is an eerie experience, as the bore opens out at intervals into caverns blasted in the rock where boats can pass. A faint glimmer of light penetrates occasionally through the ventilation shafts, and the rumble of trains in the neighbouring railway tunnel sounds through the interconnecting galleries used by the engineers of half a century later to gain access to their workings. Several of the larger canal tunnels are now impassable, although in most

cases their portals and ventilation shaft tops can still be traced. The 3,817yd Sapperton Tunnel in Gloucestershire, on the summit level of the Thames & Severn Canal beneath the Cotswolds, is waterless and in part collapsed. For some years before its closure in 1911 the canal had water supply problems, owing largely to the dry and porous limestone country through which it passed. The east portal (157/SO 966006) of Sapperton is one of the few canal tunnel entrances to have any architectural pretensions, with two niches (but no statues) flanked by finely cut pilasters. The west portal (157/SO 944034) by contrast is very simple.

The 3,795yd Lappal Tunnel between Halesowen and Selly Oak on the Birmingham Canal has, like Harecastle, suffered from mining subsidence and collapsed. So too has Norwood Tunnel, 2,895yd, on the Chesterfield Canal, and Butterley Tunnel, 3,063yd, on the Cromford Canal. The longest tunnel still in regular use on a through navigation in Britain was Blisworth (146/SP 729529 to 739503), 3,056yd, on the Grand Union Canal in Northamptonshire until the recent restoration of Parkhead locks put the 3,172yd Dudley Tunnel on a pleasure craft route. Blisworth Tunnel caused its builders a great deal of trouble, the first borings being a complete failure owing to excessive water finding its way into the workings. Work stopped in 1796, and it was not until 1802 that a new start was made with another tunnel on a slightly different line. This was eventually completed in March 1805, nearly 5 years after the rest of the canal had opened. Before the tunnel was finished, a double-track horse tramroad ran over the hill from Blisworth Wharf to what is now the foot of Stoke Bruerne locks. Time in the Blisworth area will be well spent in a visit to the Waterways Museum at Stoke Bruerne (146/SP 743500), where there are a number of open-air exhibits, including a boat-weighing machine, plus a unique collection of relics housed in an old grain warehouse covering the rich history of 200 years of canals and their people.

Of all the engineering works of the great canal builders, aqueducts have fired the imagination and excited the greatest wonder. Designed to bridge valleys that could not easily be negotiated by flight of locks, they were objects of incredulity at the time they were built. Many have survived the railway age, which had its own proliferation of great viaducts, with their splendour undiminished. Brindley's pioneer Barton Aqueduct—'the castle in the air', Smeaton called it—has already been mentioned. In fact it was the

highest and visually most spectacular of Brindley's numerous aqueducts, most of which are squat brick or masonry structures providing little more than multiple culverts for the rivers underneath. The Dove Aqueduct (120/SK 269269) on the Trent & Mersey Canal near Burton-on-Trent is a typical example. With approaches it is  $1\frac{1}{4}$  miles long and has twenty-three low arches. Others carry the Staffordshire & Worcestershire Canal over the Trent at Great Haywood (119/SJ 994229) and the Sow at Milford (119/SJ 973215).

William Edwards' precedent of pierced spandrels, which appeared in his graceful Pontypridd Bridge of 1755, was used by Benjamin Outram, engineer to the Peak Forest Canal, when he built Marple Aqueduct (101/SJ 956900) across the River Goyt. Designed to reduce the structure's self-weight, the holes also visually lighten and enhance the appearance of the aqueduct. For real elegance and panache, however, the masonry aqueducts of John Rennie are unsurpassed. Of classical proportions and detailing, his Dundas Aqueduct, a single-arch span carrying the Kennet & Avon Canal over the River Avon near Monkton Combe (166/ST 784625) in Somerset, blends into the steep wooded valley and completes the landscape in a very English way. The warm limestone provides a perfect medium for an architectural treatment of the structure appropriate to nearby Bath. Three miles to the south the canal recrosses the river at Avoncliff (166/ST 805600), but here neither the design nor the present condition of the structure are as good. The bed is dry, revealing the cement lining of the trough, while the stonework is covered with mysterious masons' marks. The sag in the centre of the river span is thought to have occurred soon after the aqueduct was completed in 1805. A larger and more severe example of Rennie's work is the Lune Aqueduct, Lancaster (89/SD 484639), which has five arches, each of 70ft span, carrying the Lancaster Canal 51ft above the surface of the river (Plate 79). Built in a hard grey sandstone, its top decorated with a handsome Doric cornice and balustrade, it too blends into the harsher north Lancashire landscape, a fine combination of functional simplicity and elegance in design. The architect, Alexander Stevens (1730-96), possibly collaborated with Rennie on its detailing.

The supreme heights of engineering accomplishment resulted from the use of cast iron in the building of aqueducts, although, unlike the first iron bridge, the earliest examples had an experimental lack of confidence. Possibly



79 John Rennie's aqueduct across the River Lune near Lancaster

the first use of the material was in a small aqueduct in Derby, now demolished, but here it only formed part of the whole structure. One month after the opening of this Derby aqueduct, in March 1796, Telford completed his crossing of the river at Longdon-on-Tern in Shropshire (118/SJ 617156) with the claim, 'I believe this to be the first aqueduct for the purposes of a navigable canal which has ever been composed of this metal.' Certainly in Telford's aqueduct (Plate 80) cast iron has real structural significance, not only in the construction of the trough itself but also in the supporting legs and partly cantilevered towpath. More important, however, was the opportunity Longdon gave Telford to test and demonstrate iron as a constructional material before building his masterpiece at Pont Cysyllte. Longdon-upon-Tern Aqueduct is a modest structure, with two full spans, one across the river, and two half spans springing from the brick and masonry abutments. The cast-iron sections are arranged in a similar manner to the voussoirs of a masonry arch and bolted together through flanges. The towpath is attached to the outside of the trough, which is thus of the minimum cross



80 Longdon-on-Tern Aqueduct, Shropshire, by Thomas Telford. The first iron aqueduct in the world, built in 1796

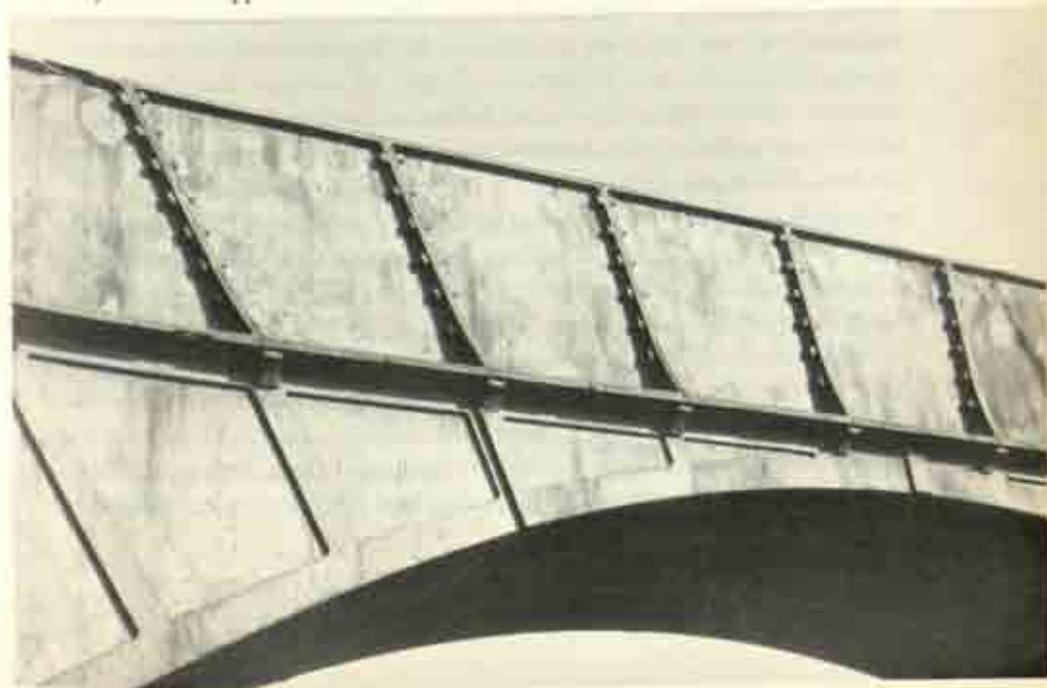
section necessary for a boat to pass, a design error that was not repeated at Pont Cysyllte. The problem with the Longdon arrangement was that great effort was needed to pull a boat through, as it was difficult for water to pass between the sides and bottom of the boat and the trough itself; at Pont Cysyllte the towpath projects inwards over a wide trough, leaving plenty of space for the water to pass.

Telford's great test came when he was resident engineer to William Jessop on the Ellesmere Canal. Here the problem was one of carrying the canal across the valleys of the Rivers Ceiriog and Dee as part of a project originally intended to tap the coal and iron district around Ruabon and the Irenant quarries near Valle Crucis, Llangollen. The aqueduct across the Ceiriog at Chirk (118/SJ 287372) has always been somewhat overshadowed by the proximity of its great neighbour, but on any other canal it would be regarded as an outstanding work. It has ten arches, each of 40ft span, carrying the canal 70ft above the river. Although the structure of the piers and arches is of stone and appears conventional in every respect, the trough itself consists of cast-iron plates, flanged and bolted together, which effectively tie in the side walls of the aqueduct. Telford appreciated that a puddle-clay-lined trough of the type used by Brindley, together with the massive masonry necessary to contain the pressure of water, would impose impossible weights on the foundations of the piers; hence the use of cast iron. The foundation stone of Chirk Aqueduct was laid on 17 June 1796 and it was completed in 1801.

The canal runs north from the aqueduct through the 459yd Chirk Tunnel (one of the first to have a towpath) towards the much larger valley of the Dee. Here, at Pont Cysyllte (117/SJ 271420), across the Vale of Llangollen, Telford carried the canal more than 120ft above the river on an aqueduct which has remained one of the great engineering achievements of all time. Compared with the alternative, of locks down each side of the valley, an aqueduct seems the obvious solution; it is the scale and sheer engineering elegance of that solution, however, which gives Pont Cysyllte a justified place amongst the industrial archaeological sights of Britain.

At Pont Cysyllte, as we have said, Telford adopted a trough construction entirely of cast iron, and the side sections, as at Longdon, are wedge-shaped to form an arch-like structure. Unlike Longdon, however, the trough is supported underneath by cross-braced cast-iron ribs (Plate 81), four beneath each span. The trough width is 11ft 10in and the deck of the towpath, 4ft 8in wide, is supported over the water surface on iron pillars. Cast-iron railings protect its outer edge, but on the opposite side the water level is only a few inches below the unprotected edge of the trough wall. Nineteen spans, each of 53ft, make a total length of 1,007ft between the approach embankments, the south one of which, with its height of 97ft at

81 Developed from Longdon, the trough sections of Telford's Pont Cysyllte Aqueduct are supported on cast-iron ribs



the tip, was the greatest earthwork in Britain at the time of its construction. The piers supporting the trough are of some interest in that, to reduce weight, they are of hollow construction from a height of 70ft upwards, with external walls only 2ft thick. Internal cross walls, used also in the hollow spandrels of Chirk Aqueduct and most of Telford's road bridges, provide the necessary structural stiffening. Today the Pont Cysyllte Aqueduct has much the same appearance as it did on its opening day in November 1805 and, although neglected and in ill-repair for many years, it is now scheduled as an ancient monument by the Department of the Environment and kept in a sound condition befitting perhaps the greatest single engineering epic of the canal age.

Another aqueduct worthy of notice is the Bearley (131/SP 162609) on the Stratford-upon-Avon Canal.

As the network of canals spread and the internal trade of the nation developed, a whole new transport industry supporting merchants, boatmen, suppliers of provisions, warehousemen, lock-keepers and lengthmen grew up also. This industry made its impact on the landscape in the form of new buildings ranging from tiny and uncompromisingly simple canal-side cottages to new townships with handsome mansions and warehouses. Few canal buildings exhibit any conscious architectural expression, and many of the smaller ones are a straightforward and economical translation of contemporary domestic traditions to new circumstances. Exceptions are inevitable and one only has to look at the Regency-style bridge-men's houses on the Gloucester & Berkeley Canal, the barrel-roofed Stratford-upon-Avon Canal cottages or the round-tower canal houses of the Thames & Severn to appreciate that here and there some architectural thought was involved. These are very much the exceptions, however, and the general rule, as exemplified by hundreds of little known and unpretentious structures, is in great contrast to the railway buildings of the following century.

At various places on the canal network junctions and transhipment points resulted in concentrations of canal-side buildings which in some cases have developed into independent communities. Some of these new towns of the canal era, small in comparison with the developments which were to occur in the age of the railways, still survive substantially intact and are among the earliest specialised industrial urban groupings in Britain. Perhaps the best known, and certainly the most highly developed of these communities, is



82 Wharf crane, Bumblehole Basin, Netherton, Dudley, Worcestershire

Stourport-on-Severn (130/SO 810710), built at the end of the eighteenth century as a trading and transshipment centre where the Staffordshire & Worcestershire Canal locks down to the River Severn. It became, in effect, an inland port between the Midlands and the sea, where goods could be transferred from canal narrow boats to river-going barges and sailing trows that voyaged down to Bristol and the South Wales ports. Here in Worcestershire Brindley 'caused a town to be erected, made a port and dockyards, built a new elegant bridge, established markets and made it the wonder not only of this county but of the nation at large.' Although the bridge was replaced by a larger cast-iron span during the nineteenth century, the centre of Stourport has changed little. It just survived the neglect following the decline of canals and is now reviving as a leisure boating centre. A fine brick warehouse with clock tower, stately merchants' houses and humble cottages all reflect the unselfconscious inspiration of the early Industrial Revolution. At Shardlow (121/SK 444304), near the junction of the Trent & Mersey Canal and the River Trent, stands another such point of interchange, built purely for commercial purposes but exhibiting through the architecture of its warehouses a functional beauty deriving from the simple use of traditional building materials. Warehouses of a more spectacular scale may be seen at

Ellesmere Port, in Cheshire (109/SJ 405775), another junction, between the Wirral line of Jessop and Telford's Ellesmere & Chester Canal and the River Mersey. Dating originally from 1795, Ellesmere Port continued to grow until the 1850s, suffered a temporary relapse, and thrived again after the completion of the Manchester Ship Canal in the 1890s, although its prosperity then no longer came from inland canal traffic. Unfortunately Telford's great general warehouse, one of the finest structures on Britain's waterways, has now gone, destroyed by fire in 1970, but other impressive structures still survive and the general arrangement and layout of the port and its facilities are worthy of examination.

Today much of the canal network, the larger part of which is no longer used at all for commercial purposes, is undergoing a transformation. Groups of enthusiasts working in cooperation with the British Waterways Board are energetically putting many of the more scenic routes back into commission for leisure purposes; the names and addresses of the leading societies and coordinating bodies are given in Appendix 3. Already the northern section of the Stratford-upon-Avon Canal is operational again, restored from a state of complete dereliction, and working parties are active on canals such as the Peak Forest, the Kennet & Avon and the Caldon. Moreover, the amenity value of waterways is also being recognised by local authorities, and enterprising conservation schemes have been carried out in the Little Venice area of Paddington; at Farmer's Bridge, Birmingham, the junction of the Birmingham Canal Navigation main line and the Birmingham & Fazeley Canal; and at the nearby Gas Street basin. Tree planting, landscaping and the rehabilitation of derelict canal-side cottages all contribute to the success of schemes which amply demonstrate that the canal in an urban area does not have to be an eyesore.

Although the future of the narrow canal system must lie in amenity usage, there are a number of commercial waterways actively in operation and employing in many cases up-to-date cargo-handling techniques. Centred on the Humber are the Aire & Calder Navigation, giving access for 540 ton barges to Leeds and Wakefield, and the Sheffield & South Yorkshire and Trent Navigations, running to Rotherham and Nottingham respectively. The Weaver Navigation can take sizeable ships, as can the Gloucester & Sharpness Ship Canal, a link in the navigation of the Severn up to Stourport. The South East has the Thames and the River Lee. Only on these kinds of

waterway, and of course the Manchester Ship Canal, can further cargo-carrying developments be expected. On the majority of inland navigations the commercial traffic which brought them into existence in the second half of the eighteenth century has gone for ever, and only the archaeological remains reflect the buoyant enthusiasm, panache and grinding labour of the canal promoters, their engineers and navvies.

## 15 Railways

THE railway captured the imagination of the people as did no other form of industrial technology. In the country of origin of the steam locomotive, the UK, and elsewhere too, the opening of a new railway line was almost always an occasion for festivities and rejoicing. A century or more later the demise of steam on British Railways in the late 1960s evoked a wave of nostalgia quite without precedent. Today more than 900 steam railway locomotives are preserved in Britain in museums, on privately owned branch lines, or merely on short stretches of track where they can be put into steam for a few hours at a weekend. The railway was the first form of transport with which the mass of the populace had any contact, and as such it has been regarded as rightfully subject to both public criticism and affection. Criticism of railways and their methods of operation has always been a fashionable sport, while affection, of almost equally long standing, has centred largely around the mystique of the steam locomotive. Much of the enormous bibliography which railways have generated is also devoted to steam power, so in this chapter the civil engineering works, the 'real estate' of the railways, will be considered primarily.

The idea of using rails for vehicular traffic dates back much further than the steam locomotive, and this early period, which might be called the 'prehistory' of railways, can be a fruitful area of study for the industrial archaeologist. The profusion of field remains and frequent wealth of documentary and cartographic information has enabled a remarkably complete picture to be built up of the role of the railway before the coming of steam power. Specifically archaeological evidence has made a major contribution. The first use of rails in Britain was probably in the late sixteenth century in Shropshire, Nottinghamshire and Northumberland. In these areas lines were built for moving coal relatively short distances to rivers or the coast, where boats could load it. The rails were made of wood, as at first were the wheels that ran on them. Not until the second quarter of the eighteenth century were iron wheels employed and wooden rails faced with iron plates to reduce wear.

The first known use of iron rails was in 1767. Cast at Coalbrookdale in Shropshire, they were thereafter used extensively on local lines in and around coal workings and also in South Wales. They were 'edge rails', designed for use with flanged wheels, and were probably laid on timber cross sleepers. In the 1780s iron rails of an 'L' section—with the flange cast on the rail instead of on the wheel—were introduced and quickly became popular. In South Wales, for example, some 300 route miles of this 'plateway' were in use in the early years of the nineteenth century, and in Shropshire, the birthplace of the iron edge rail, the L-section plates became almost universal (Plate 83). The new rails were supposedly stronger than the edge rails, but it is doubtful if the other claimed benefit—that the vehicles could be used off the rails in colliery yards—was found to be particularly useful.

A note on terminology is relevant here, as a variety of sometimes conflicting nomenclature has been applied to these early pre-locomotive railways. All were technically railways, in that the vehicles ran on rails, although the term 'railroad' was more widely used before 1830 and was later adopted as standard in North America. In the North of England particularly, where edge rails were favoured, 'waggonway' was used, and this persisted until relatively recently. Elsewhere, however, 'tramroad', 'dramroad' and 'tramway' were after 1790 applied specifically to lines employing L-section rails. The origin of these terms is uncertain, but they possibly derive from

83 Dual-gauge cast-iron plateway, Coalbrookdale, Shropshire



the old German or Scandinavian words for a beam of wood, a 'traam', which might have been the rail. Certainly 'trammy' and 'tram' were applied to the vehicles themselves in the sixteenth century. There is no evidence to support the theory that 'tramroad' had any connection with the name of Benjamin Outram, one of the chief protagonists of the cast-iron rail. Later in the nineteenth century, of course, the word tramway was revived in a different context, to describe the new passenger-carrying street tramways, first horse-drawn and later electrically propelled. Yet another word specifically applied to the early railways using L section iron rails was 'plateway', from which the modern term 'platelayer' originates.

Three distinct forms of pre-locomotive railway developed before 1830 and all were in operation side by side at the outbreak of the steam-powered railway revolution. The first type, as we have seen, comprised lines built and usually owned by coalowners to connect their collieries with existing river or sea transport. Successors to these are still operated, as conventional railways, by the National Coal Board in County Durham, one of the longest systems being the Bowes Railway, with lines radiating south-westwards from Jarrow Staithes (78/NZ 353650) towards Pontop. The second type of tramway was built as an adjunct to a canal and was usually owned by the canal company. Tramways were less restricted by topography than canals, and from the 1780s onwards were built in large numbers as feeders to canal branches. The third variety came into being on 26 July 1803 when the Surrey Iron Railway was opened as a double-track public tramway from the Thames at Wandsworth to Croydon, 9 miles away. This line, which was seen as a possible first stage in a route from London to Portsmouth, heralded the era of public lines promoted as common carriers by separate railway companies.

Of the colliery-owned and operated lines, numerous remains survive, particularly in the North East. One of these remains, at Tanfield in County Durham, is the Causey Arch, built in 1727 and generally accepted as the oldest existing railway bridge (78/NZ 220517). It is a spectacular masonry structure about 60ft high, its span of 103ft the fifth largest of any masonry railway bridge in Britain. Near Whitfield, also south of the Tyne, early eighteenth-century tramway earthworks are to be seen at High Spen (78/NZ 137596).

One of the earliest surviving railway buildings is a weigh-house of 1799

at Brampton Sands, Cumberland (76/NY 550600), on the alignment of the Brampton Railway, an extension of the Tindale Fell Waggonway opened about 1775. Near Kirkhouse, cuttings and embankments are easily traceable (76/NY 567599), while the earthworks of the Parker waggonway, south of Whitehaven harbour, can be seen at Monkwray Brow (82/NX 969167). This line, owned by Sir James Lowther, was opened in 1738.

The 6 mile Middleton Colliery Railway in Leeds, dating from 1758, was built under Parliamentary Acts and is thus claimed to be the first officially authorised railway. Not a great deal can be seen of the original alignment, but the incline, known as the 'Old Run', can still be traced and stone sleepers are visible on Hunslet Moor where they have been re-used as platform edging. Three miles of the railway are operated with steam locomotives by the Middleton Railway Trust. Some of the line is protected by the National Trust.

Lines feeding canals are well represented archaeologically and, unlike the colliery lines, which are mainly in the north, they are concentrated primarily in midland and southern England where the canal network was densest. One of the earliest examples ran from the Froghall basin terminus of the Caldon Canal in Staffordshire (111/SK 028477) to limestone quarries at Cauldon Lowe. The canal itself, a branch from the Trent & Mersey, at Etruria passes through the Churnet valley and some of the finest scenery in north Staffordshire. It is being restored by the Caldon Canal Society. Remains of the tramway, built originally in 1777, and realigned in 1783 and again in 1802 (by John Rennie), are numerous. At Woodcock there is a ruined bridge and at Whiston a complete bridge, an embankment and the remains of one of the three self-acting inclined planes (111/SK 029476).

In Derbyshire extensive remains can be seen of the Peak Forest tramway engineered by Benjamin Outram and opened in 1796 from Bugsworth (now politely renamed Buxworth) basin (111/SK 020820) to Chapel-en-le-Frith and limestone quarries at Doveholes. The 85yd tunnel at Chapel Milton (111/SK 058817) must be the earliest railway tunnel in the world. Much of the alignment can be traced, including long lines of stone sleeper blocks. A wagon is preserved in York Railway Museum.

Another well preserved line extended from Willesley on the Ashby-de-la-Zouch Canal in Leicestershire to limestone quarries at Ticknall and Cloud Hill in Derbyshire. The best sites are in Ticknall itself, where a bridge

crosses the main street (121/SK 356240) and a 138yd cut-and-cover tunnel has been put in to preserve the amenities of the approach to Calke Abbey (121/SK 355238). On the Somersetshire Coal Canal sparse remains can be seen of an inclined plane tramway that was laid as a temporary link at Combe Hay (166/ST 748604) while a flight of twenty-two locks was being built. The alignment of a similar type of tramway, later used as a bridle path, links the two ends of Blisworth Tunnel (146/SP 729529 to 739503). It was used between 1800 and 1805 to connect the two ends of the canal while the tunnel itself was under construction. A permanent inclined plane for the transhipment of goods from canal boats to wagons connected the terminus of the Tavistock Canal above Morwellham with quays on the River Tamar 247ft below (187/SX 446698). It was opened in 1817. The remains of slate sleepers are preserved in the Morwellham Quay Centre for Recreation & Education.

Of the lines built to link sections of canal, the longest was the Cromford & High Peak Railway in Derbyshire, opened in 1831 to join the Cromford Canal with the Peak Forest Canal near Whaley Bridge. Tapping the limestone resources of the Peak, it spanned 34 miles of central Derbyshire, reaching at its summit a height of 1,266ft above sea level. Inclines connected the central sections with the termini. Much of the line, which was using steam locomotives as early as 1834, remained in use as a railway rather than a tramway until 1967. Miles of its trackbed can be walked, including the two great inclines—Middleton and Sheep Pasture. At Middleton Top (111/SK 275552) the steam winding engine is preserved.

The biggest mileage of canal-owned tramways was in South Wales, where almost all the companies had extensive feeder networks. The Monmouthshire Canal, for example, owned 14 route miles of railway, comprising nine separate lines. A particular advantage many of these coal-carrying lines enjoyed was that the down gradient favoured the loaded trains. There is a bridge at Blaenavon in Prince Street, and a milepost at Abersychan. Also in Monmouthshire, although not on canal-owned lines, are the 2,050ft Pwll-Ddu Tunnel, opened in 1815 partly through old mine workings (141/SO 248114), and a fine bridge carrying an incline (Plate 84) on the Redbrook branch of the Monmouth Railway, opened in 1812 (142/SO 537103).

It was inevitable that the success of the tramway as an aid to canal and river transport should result in its use as a common carrier in its own right



84 Tramway incline bridge in the Wye Valley at Redbrook, Monmouthshire

for providing cross-country links. The Surrey Iron Railway of 1803 was the first and others followed quickly. By the 1820s several of these horse-drawn public railways were being authorised each year, mainly for freight haulage, although as early as 1807 the Oystermouth Railway running along the coast between Swansea and the Mumbles was carrying fare-paying passengers. It is important to appreciate that the railway proved its value, and perhaps even its superiority over the canal, before the introduction of steam power, and that by the mid 1820s inter-city routes were being proposed. Lines such as the Sirhowy (1802), the Severn & Wye (1809), the Mansfield & Pinxton (1817) and the Stratford & Moreton (1821) were all conceived as horse railways, and as such were highly successful. Some of their major civil engineering works remain, such as the bridge across the River Avon at Stratford (144/SP 205548) now used as a footbridge. Some re-erected track of the Surrey Iron Railway can be seen on its original alignment at Purley Rotary Field (170/TQ 316622) and some more, though not on the old route, at the *Joliffe Arms* (170/TQ 290543) and outside Wallington branch library (170/TQ 288638). In Ayrshire there are notable tramway bridge remains at Fairlie (67/NS 383369), where the Kilmarnock & Troon Railway crossed the River Irvine, and the remains of an early skew bridge on the Doura branch of the Ardrossan & Johnstone Railway (59/NS 338423).

It took just 25 years for the locomotive to prove itself the most suitable means of applying the power of steam to railways. Richard Trevithick (1771-1833) built what is generally considered to be the first steam railway locomotive at the Coalbrookdale Ironworks in Shropshire in 1802, and 2 years later operated a similar machine successfully on the Penydarran Railway in South Wales (154/ST 083969). For a quarter of a century the locomotive developed spasmodically, in competition with the use of stationary steam engines to haul trains with cables, until in 1829 the railway engineer George Stephenson, in an effort to decide which form of power to apply to the Liverpool & Manchester Railway, then in an advanced stage of construction, proved beyond all doubt that the steam engine should move with the train. The Rainhill trials of 1829, won by Stephenson's own *Rocket*, were the turning point in the fortunes of the locomotive and the effective beginning of the railway revolution.

A number of 'pre-Rainhill' locomotives are preserved, and they demonstrate clearly the evolution of design. Trevithick was a pioneer of high-pressure steam in stationary engines—that is engines operating at a pressure of 20-25lb per sq in—and it was this use of high pressure that provided the key to the successful development of the locomotive. The great size of the low-pressure beam engine, and more particularly its enormous condensing apparatus, prevented its use as a mobile power source. Trevithick's own locomotive, which has not survived, employed a horizontal cylinder of small bore and long stroke rather like his stationary engines. Similarly other early locomotives were adaptations of available high pressure designs. *Wylam Dilly* in the Royal Scottish Museum, Edinburgh, and *Puffing Billy* in the Science Museum, London, both dating from 1812-13, are in effect grass-hopper engines on wheels, whereas the Hetton Colliery locomotive of 1822, preserved at the York Railway Museum, and the Killingworth locomotive in the Newcastle Museum of Science & Engineering have the more direct form of drive of the Maudslay table engine. By the late 1820s locomotives were being built with pistons connected directly to their wheels through piston and connecting rods. *Sans Pareil* and *Rocket*, both contenders at Rainhill and both preserved in the Science Museum, London, are of this type. More important at this date, however, was the way in which the boiler was developing, with numerous tubes between firebox and smokebox giving it a good steaming rate. It was primarily the superiority of its boiler



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TO THE MEMORY OF THOMAS SCAIFE

late an Engineer on the Birmingham and Gloucester Railway who lost his life of Bromsgrove Station by the Explosion of an Engine Boiler Tuesday the 10th November 1840.

He was 26 Years of Age highly esteemed by his fellow workmen for his many amiable qualities and his Death will be long lamented by all those who had the pleasure of his acquaintance.

The following lines were composed by the workmen present as a Memorial of the worthiness of the Deceased.

My engine now is cold and still. My fanges all refuse to guide.  
No water does my boiler fill. My smoke also though even to drag  
My valve affords its flame no more. Refuse to aid the heavy Grand  
My days of usefulness are o'er. No more I'll work my engine  
My wheels sleep their usual round. My reason is now restless in death  
No more my guiding hands they bend. Like's reason's not much stronger and  
My axle tree has lost its force. In death I'm staid and rest at last.  
Its steel and thrilling axles are gone. Farewell fare friends and men to come.  
My engine are now thrown upon waste. In Christ I'll sleep as I sleep.

THIS STONE WAS ERECTED AT THE JOINT EXPENSE OF HIS FELLOW WORKMEN 1840

PRATTE



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TO THE MEMORY OF JOSEPH RUTHERFORD.

LATE ENGINEER TO THE BIRMINGHAM AND GLOUCESTER RAILWAY, COMEYANT

who Died Nov 11 1840 Aged 32 Years

Oh Reader stay and cast an eye  
Upon this Grave wherein I lie  
For cruel Death has challenged me  
And soon alas will call on thee  
Repent in time make no delay  
For Christ will call you all away

My time was spent like dawns and  
Beyond all cure my glass is run

85 Gravestones in Bromsgrove Churchyard, Worcestershire, of two enginemen on the Birmingham & Gloucester Railway killed by a boiler explosion in 1840

that gave Rocket the edge over its competitors at Rainhill. Within 5 years Stephenson engines such as Northumbrian and Planet had established the general form of the locomotive, which was to survive virtually unaltered until the demise of steam power on British Rail in the 1960s.

The success of the steam locomotive was very much a personal triumph for George Stephenson (1781-1848) and his son Robert (1803-1859). In 1825 the elder Stephenson had engineered the first public railway on which steam locomotion was used, although initially only on a small scale, between Stockton & Darlington. Five years later he built the Liverpool & Manchester, the first railway to carry passengers and the first to be completely steam-worked from the beginning. Both were built to the now standard gauge of 4ft 8½in. The origins of this gauge are obscure but it seems likely to have evolved from the tramways of the North East, a natural derivation from the

width between pairs of horse-drawn cartwheels. The Stephensons were unrivalled as railway engineers in the early 1830s, and it was their appreciation that one day all local lines would be joined together in a nationwide network that led to the adoption of the 4ft 8½in gauge throughout most of the country. Only one major line, the Great Western, brainchild of the brilliant engineer Isambard Kingdom Brunel, did not adopt standard gauge.

Lines such as the Stockton & Darlington and the Liverpool & Manchester, and other contemporaries like the Canterbury & Whitstable and the Leicester & Swannington, had been built to satisfy specific local requirements for the haulage of goods, but in the event the traffic pattern was quite different; passenger receipts were more than double freight takings on the L & MR right down to the mid-1840s, and the national consciousness suddenly became aware that big profits were there for the taking. By 1836 nearly 2,000 route miles of railway had been sanctioned, including most of what were to become the major trunk routes focused on London. The first of these was Stephenson's superbly engineered London & Birmingham, to be quickly followed by routes from the capital to Southampton, Brighton

86 Gatekeeper's cottage at Glenfield level crossing, Leicester & Swannington Railway, 1832. Demolished



and Bristol, by an extension of the L & BR northwards into Lancashire, and by a collection of small lines which eventually linked London with York, the North East and Scotland. Three of these—the Midland Counties, the Birmingham & Derby Junction and the North Midland—amalgamated in 1844 to form the Midland Railway, one of the largest companies not to have a London terminus, a fact which was significantly to alter the skyline of the Euston Road a quarter of a century later.

The 'railway revolution' born out of the success of lines like the Liverpool & Manchester and London & Birmingham got going in earnest in the 1840s. It was one of the most remarkable phenomena of the whole period of Britain's industrialisation. The landscape changes the railway brought about were more widespread and more fundamental than those created by any other industry, and this is reflected today in the profusion of remains. The direct effects could be seen in terms of embankments and cuttings, viaducts and tunnels, on the one hand, and by new towns such as Crewe and Swindon, which were creations of the railway companies themselves, on the other. Less direct but just as obvious was the increase in general economic activity brought about by the improvement in transport, a trend that had begun with canals and accelerated rapidly with the coming of railways. Railways performed the same basic economic function as canals, shifting bulk goods at low cost. In addition, however, they offered the equivalent, on a larger scale, of the best eighteenth-century post roads, which provided rapid communication for people, mail and specialised freight.

The enormous impact the railway had on the economy and the scale of its development are worth studying. To the success of the second-generation steam railways—early main lines like the London & Birmingham of 1838 and the Great Western of 1841—may be directly attributed the enormous boom in railway building which reached a peak in 1848, when 1,253 miles were opened. The peak years for sanctioning construction were 1845 (2,816 miles), 1846 (4,540 miles) and 1847 (1,295 miles). Many lines promoted in these frantic years of the mid-1840s were never built, so that by 1851, when a total of 12,698 miles had been sanctioned, only a little over half (6,803 miles) had been completed. This in itself was a formidable figure. During the years 1846-8 railway investment was absorbing 5-7 per cent of the national income, about half the total capital investment and equivalent to about two-thirds of the value of all exports. It entailed a wage

bill of £16 million for a construction force of 250,000, and by 1850 there were 60,000 employees running the new railways. The significance of railway building in the national economy was such that during the late 1840s and the 1850s the railway industry itself could be regarded as a major factor in determining the cyclic movements of the economy. Iron, coal and brick prices moved in parallel with the timing of railway contracts; indeed the demands of the railways were almost solely responsible for the enormous growth in iron rolling mills during the 1850s and 1860s. By 1850 railway locomotives were burning 1 million tons of coal a year, and, although this was only some 2 per cent of national production, the railway-stimulated industries all consumed their share too. Railway development led directly to increased urban growth, while the railway industry itself became one of the greatest breeding grounds of the new technocrats who were to be the mainstay of Victorian industrial might. The effect on other transport systems was cataclysmic. By the 1850s the long-distance road coach had been virtually eliminated and most canals rendered unprofitable. There was a real deterioration in road conditions in many parts of Britain as the turnpike trusts were wound up and road maintenance became again the responsibility of a reluctant parish.

With the completion of the Great Northern main line between King's Cross and York in 1852, nearly all the major routes of the modern railway system in England had been developed. All the major industrial areas, cities and ports were linked by a network which, although its individual components belonged to dozens of separate companies, could be regarded as a national railway system. There was still much filling in of the gaps to be undertaken, however, and both Wales and Scotland, with the exception of the industrial lowlands, were virtually without railway lines. By 1914, its approximate peak, the total network of the United Kingdom was 23,000 miles. The £1,300 million invested in the system had created the most expensive, extravagant, wasteful and at the same time spectacular symbol of Victorian success.

British railways were very costly to build, and at an average of £40,000 per mile were three or four times as expensive as American and most continental systems. They became an engineer's paradise, with lavish standards of finish to major bridges and viaducts, tunnel portals and stations. There were real reasons, however, for the heroic quality of much railway engineering

and architecture, particularly in the late 1830s and early 1840s. Firstly, engineers such as the Stephensons and Brunel, while consciously designing for the future, had to allow for the limited locomotive tractive effort and relatively underdeveloped mechanical knowledge of their day. So they built lines with easy gradients—the London & Birmingham had a ruling gradient of 1 in 330—and therefore committed themselves to building heavy earthworks. Secondly, there was the problem of making the railway a socially acceptable means of travel, and this was solved by magnificent termini, architecturally acceptable in a city environment, line-side stations of a vernacular or domestic style often beautifully attuned to their geographical and social surroundings, and major engineering structures handled with a panache and yet sympathy for landscape unequalled to this day. Euston or Temple Meads had the same function as the airline terminals of today, being designed not merely to book the passenger on to a train but to inflate his ego, enhance the prestigiousness of the railway experience, and reassure him that it was not as dangerous as he imagined.

Both the Stockton & Darlington and the Liverpool & Manchester railways were built before this attitude had become fashionable—they were after all built primarily as goods lines. On the S & DR stone sleeper blocks can still be seen on disused inclines at Brusselton (85/NZ 195255) and Etherley and there are the earthworks of abandoned stretches of the line at Low Etherley (85/NZ 170289) and North Leaze. A fine stone three-arch bridge by Ignatius Bonomi crosses the River Skerne at Darlington North Road (85/NZ 289157); this is perhaps the first bridge of the steam age, and although it has been widened, the south face is original. Another bridge, of cast and wrought iron, crossed the River Gaunless near West Auckland but it was removed in 1901 and can now be seen in the York Railway Museum—one of the first pieces of conscious industrial archaeological preservation. Here too is an S & DR chaldron wagon, very like the thousands that worked the colliery lines of the North East until relatively recently; examples can also be seen at the North of England Open Air Museum, Beamish. Two locomotives from the line—*Locomotion* of 1825 and *Derwent* (Plate 87) of the late 1830s—are preserved at Darlington Bank Top Station (85/NZ 294140).

The masonry arch in a variety of shapes and sizes was by far the commonest type of railway bridge structure until the 1860s and 1870s, when fabricated



87 Stockton & Darlington locomotive *Derwent* preserved at Darlington Station

girders began to appear. The Liverpool & Manchester has two fine masonry viaducts by George Stephenson in the nine-arch Sankey Viaduct near Warrington (100/SJ 569947) carrying tracks 70ft above the valley floor, and a smaller one of four arches at Newton-le-Willows (100/SJ 591954). On the same railway the skew arch bridge carrying the main Liverpool to Warrington road over the line at Rainhill (100/SJ 491914) has been widened, but the basic structure of the arch with its intricate compound curves is still intact beneath the present deck. Little remains of early station buildings, although the original L & MR eastern terminus at Liverpool Road, Manchester (101/SJ 830978) still has some of the original offices and reception areas. Line-side buildings were domestic in style, influenced if anything by contemporary road and canal architecture. The cottage situated in Bridge Road, St Johns, Stockton-on-Tees, on the S & DR, and claimed to be the first railway book-

ing office, is now administered by Teesside Museums. There is a building with more obvious lineage at Bagworth (121/SK 446091) on the Leicester & Swannington Railway, opened in 1832; with its half-hexagonal end and panel for a non-existent tollboard, it is a perfect replica of a contemporary tollhouse and is now, since the demolition of the gem at Glenfield, the only one of its kind on the line and a curious example of the transfer of style from one transport system to another.

The remains of the first inter-city main lines, like the London & Birmingham and Great Western, are surprisingly common, and as spectacular today as when J. C. Bourne recorded them in his dramatic series of lithographs of the early 1840s. At Tring, Hertfordshire (159/SP 940137) the great cutting (Plate 88) is 2½ miles long and 60ft deep, and at Roade another bites 70ft deep into the Northamptonshire hills (146/SP 750525). The greatest work on the L & BR, however, is Kilsby Tunnel (133/SP 565715 to 578697); nearly 1½ miles long it is marked on the surface by the brick towers of its ventilating shafts, the largest of which are 60ft in diameter. All these works reflect

88 Tring cutting, Hertfordshire, cut in the late 1830s for the main line of the London & Birmingham Railway and subsequently opened out to four-track width



George Stephenson's insistence on gentle gradients; had the line been built 20 years later, Kilsby Tunnel could have been avoided altogether.

Stations on the L & BR have not fared so well. The destruction of the Euston arch, Philip Hardwick's magnificent gateway to the world's first main line railway, was a major loss. It is perhaps some consolation that Euston's demise was a major contributory factor towards creating an informed and articulate lobby prepared to argue the case for preservation. Indeed the industrial archaeologist of the future may well look back on the loss of Euston as the first great sacrificial price that had to be paid before other monuments of Britain's industrial heritage could be spared. North of Euston, however, at Camden, stands a very tangible memorial to the early days of the L & BR—the roundhouse locomotive shed (160/TQ 282843) designed by George Stephenson and built in 1837 at the head of the mile-long incline up from the terminus itself. Initially the trains were cable-hauled out of Euston, locomotives taking over at Camden for the journey north. Hardwick's other terminus building, at Curzon Street, Birmingham (131/SP 080871), with its Ionic columned façade and office block substantially intact, maintains a dignity and presence truly monumental in character amid the grimmest of urban surroundings. Birmingham could ill afford its loss.

Another early main line built in the grand manner, and of which considerable evidence survives today, was the Great Western connecting Bristol with the Metropolis. Conceived in Bristol and engineered by Isambard Kingdom Brunel, only 30 years old when the railway's Act was passed in 1836, the Great Western was part of a splendid vision, the child of a brief spell when Bristol recalled its former glories and saw itself again as the Gateway to the West. Brunel alone among the engineers of his period rethought the railway from basic principles and argued that in engineering terms a much wider gauge—he adopted 7ft—would provide a better ride, permit higher speeds, give greater carrying capacity and allow much more latitude for future development than 4ft 8½in. There can be no doubt that he was right, in engineering terms, but unfortunately there were other factors to be considered. Goods and passengers had to be changed wherever the standard and broad gauge met, and there was no possibility of through-running trains or rolling stock. By the end of the nineteenth century, when Britain had the second densest rail network in the world (after Belgium), the Great Western had to capitulate and change to the standard gauge, an

operation which was completed in 1892.

The journey west from Paddington is a triumphant succession of major civil engineering works culminating in the minute (by modern standards) but still surprisingly complete terminus at Temple Meads, Bristol. The first Paddington station has gone, replaced by the magnificent multiple-aisle transepted train shed of 1854, designed by Matthew Digby Wyatt. The transepts give the whole roof structure a remarkably complex appearance, but they did once fulfil a useful purpose, providing clearance for carriage traversers, now extinct mechanisms for moving individual vehicles laterally from one track to another.

The first major work westwards from Paddington is Hanwell Viaduct (160/TS 150840) spanning the valley of the Brent in eight yellow brick arches and demonstrating in a restrained way Brunel's predilection for the Egyptian style, to be seen also in his Clifton suspension bridge at Bristol. The arms of Lord Wharncliffe were placed on the south face in honour of one of the staunchest supporters of the Great Western Bill in Parliament. At Maidenhead comes the first crossing of the Thames (159/SU 901810), on two 128ft semi-elliptical arches, their rise of only 24ft 6in making them the flattest brick arches constructed at that date. Westwards again the line passes through the great cutting at Sonning (159/SU 759743), originally planned as a tunnel some 2 miles long, before reaching Reading and the route up the Thames valley towards Didcot (Plate 89). In following the Thames the line departs from the traditional route to the west, taken by the Bath Road and the Kennet & Avon Canal, to pursue a more northerly course across north Wiltshire to a summit west of Wootton Bassett. The descent into the valley of the Avon through the 2 mile tunnel at Box is the climax of the line. Box Tunnel, with its gradient of 1 in 100, was to be for Brunel what Kilsby had been for the Stephensons—the civil engineering *tour de force* of the line, the one major work on the successful completion of which the railway depended. In addition to the engineering problems of this greatest railway tunnel so far attempted (it killed over 100 men during construction) almost every conceivable bad omen was called down upon it, with predictions of wholesale death and disaster for any who ventured inside. But the tunnel was completed, 9 months behind schedule, in the summer of 1841. At its western end (156/ST 829689) Brunel, always susceptible to a setting in which to make a grand gesture, created a portal that



89 Great Western Railway broad-gauge standard-gauge goods transfer shed, Didcot, Berkshire

epitomises the early railway age and the man. Its dignified architectural style and enormous proportions sit perfectly in the cutting east of the Bath Road, which the railway here rejoins. Only Brunel could stage-manage this supreme advertisement for the new Great Western Railway at the entrance to that 'monstrous and extraordinary, most dangerous and impracticable tunnel at Box'. West of Box the line continues its descent towards Bath, which it enters through a beautifully finished cutting along the edge of Sydney Gardens and a great viaduct of seventy-three arches on which stands the station, now much altered. Between Bath and Bristol are five more tunnels (there were originally seven but two were opened out in 1894), a twenty-eight arch viaduct at Twerton and four large bridges now all substantially modified. In Bristol itself is the grand finale, the terminus at Temple Meads, the most complete early railway terminus in the world, with

its 72ft span timber-roofed train shed and Tudor-style office block fronting on to Temple Gate. Although the train shed is fulfilling a new function as a car park for the later Temple Meads, completed in the 1870s, the office block is virtually unused and under threat of demolition for the inevitable road widening. No railway station extant today is more deserving of preservation.

An aspect of any major railway project, for which no real precedents in other forms of transport existed, was the provision of repair and maintenance facilities for locomotives and rolling stock. On the London & Birmingham a works was established approximately halfway along the line at Wolverton, and on the Great Western a similar 'green field' situation was chosen by Brunel about a mile north of the market town of Swindon in north Wiltshire. On Brunel's Great Western over 70 of the total of 118 route miles had a ruling gradient of less than 1:1,000, on 40 more this was increased to 1:750 and only in the western section, between Wootton Bassett and Bath, were steep gradients encountered at all, the 3 miles including Box tunnel involving the sharpest section at 1:100. The choice of Swindon as a suitable place to set up a locomotive works thus stemmed not only from its approximate mid-point position. It was a place where locomotives suitable for the heavy gradients of the western section could be changed and also, as an added advantage, a point where the projected branch to Gloucester and Cheltenham could meet the main line.

Swindon was the first of the major railway towns, for Wolverton was eventually to be eclipsed by Crewe. Despite Swindon's enormous industrial diversification in the last 10 years or so, it retains something of the flavour of the Great Western about it. Neat terraces of workers' houses faced in the local stone were built by the railway company around the entrance to the works on the south side of the line, and these, together with the institute and church, formed a new town second only perhaps to Saltaire near Bradford as an example of planned urban development. One of these railway-built buildings, possibly designed by Brunel himself, houses the Great Western Railway Museum, which contains a small but comprehensive collection of locomotives, including the replica broad-gauge *North Star*, and innumerable small items which add up to form the complex organism that was a railway. The Great Western name is still kept alive by numerous preservation societies, and its locomotives and stock are run at Didcot by the Great

Western Society, on the Dart Valley Railway in Devon and on the Severn Valley Railway, centred on Bridgnorth, Shropshire.

Curiously, some of the most widespread pieces of archaeological evidence of the early days of the Great Western are sections of broad-gauge rail designed by Brunel and made redundant by standardisation of gauge. Brunel designed his broad-gauge track with a continuous longitudinal timber sleeper beneath each rail to give good but resilient support, and these longitudinals were tied every 15ft and the ties initially piled into the trackbed. On the timbers were laid rolled-wrought-iron rails of 'top hat' section fixed down by bolts through the base flange or 'brim' of the hat. It seems probable that Brunel devised this particular section to give maximum strength for a minimum amount of iron, and also possibly to arrive at a section that could be rolled satisfactorily without suffering the lamination experienced on other types of rolled iron rail at this period. With the eventual adoption of standard 'I' section bullhead rails, first in iron and later steel, the 'bridge rail', as Brunel's rail was called, became redundant; but it was re-used for fencing stakes and as such can be found all over the old Great Western system, as far west as Cornwall and Pembrokeshire and north-west in Cheshire on the line to Birkenhead Woodside. A similar rolled section, although probably not re-used rail, can be seen in the roof girders of the Swindon railway works drawing office. Another type of rail, used on the Great Western and by some standard-gauge companies and devised by W. H. Barlow, aimed at dispensing with the longitudinal timber baulk altogether, the rail being laid directly into the ballast. Of an expanded 'top-hat' section with a base width of 12in, it was not a great success, but sections of the rail can still be found quite frequently in the form of gate-posts to goods and coal yards, mainly on old Great Western lines.

Although few other railways were to be built throughout to the standards of the Great Western, dozens of major engineering structures and thousands of minor ones dotted the immense network of lines which grew up throughout the remainder of Victoria's reign. Some 25,000 bridges were added by the railways to the British landscape between 1830 and 1860 alone. The majority still survive, many in substantially original condition and most still in use. A number of bridge types have already been mentioned and the point made that in the early period of railway building brick or masonry arch structures were by far the most numerous. The largest masonry span

in Britain is the 181ft Ballochmyle Viaduct (67/NS 508254), built in 1848 on the Glasgow & South Western Railway between Kilmarnock and Dumfries to the designs of the Scottish engineer John Miller. Almost as spectacular is the seven-arch Victoria Bridge across the River Wear in Sunderland (78/NZ 396575), completed in 1838 by the Durham Junction Railway, with a largest span of 161ft.

Most major brick and stone-arch bridges on British railways have multiple arches with spans ranging from 25 to 50ft. A fine early example with unusually large spans of 60ft is the twenty-arch Dutton Viaduct (109/SJ 583764) built by George Stephenson and Joseph Locke to carry the Grand Junction Railway linking Birmingham with Manchester and Liverpool across the valley of the River Weaver in Cheshire. By far the longest arch structure, however, was built as late as the 1880s, when the Midland Railway put in its alternative route to the Soar valley line running from Kettering via Oakham and Melton Mowbray to Nottingham through the rich Jurassic iron-ore fields of east Leicestershire. Harringworth Viaduct (133/SP 914975) across the Welland Valley, Rutland's only major industrial monument, is some 3,500ft long and has eighty-two brick arches. It is little used today except by occasional mineral trains.

By the end of the nineteenth century almost all bridges were being built in wrought iron or steel, but concrete was just sufficiently developed and accepted as a building material to be used in some of the last viaducts constructed on British lines. There is an example at Glenfinnan (35/NM 910813) on the Mallaig extension of the West Highland Railway, opened in 1898, which has twenty-one arches each of 50ft span and is built on a curve of 12 chains radius (Plate 90). The concrete is not reinforced but simply poured into timber form-work, the curve being achieved by tapering the piers so that simple semi-cylindrical arches could be used. To allow for any possible differential settlement of the piers, a sliding joint consisting of two steel plates is incorporated in the crown of each arch, but no noticeable movement has occurred since the bridge was built.

Of the variety of metal bridges built to carry railways, the earliest large-span types were beam structures made in the form of tubular or plate girders. The Britannia tubular bridge (107/SH 542710) built by the Chester & Holyhead Railway across the Menai Straits was the most important of these, not merely as a railway structure but as a landmark in the evolution of



90 Mass-concrete viaduct at Glenfinnan on the Mallaig extension of the West Highland Railway, 1898

civil engineering. It marked the first use of the beam principle for a long span bridge, and its design and construction was the culmination of the model experiments carried out by William Fairbairn (1789–1874) and their translation into usable theoretical terms by Eaton Hodgkinson (1789–1861). Robert Stephenson, engineer to the Chester & Holyhead, approached Fairbairn, a shipbuilder and engineer of Millwall, London, as early as April 1845 regarding the desirable shape of the tubular deck of a wrought-iron suspension bridge he was proposing. By December of 1845 Fairbairn, in consultation with Hodgkinson, who was later appointed Professor of Mechanical Principles of Engineering at University College, London, had evolved a rectangular section beam design, cellular at the top and bottom to resist any possible collapse through compression or failure through tension. Fairbairn advocated the use of the tubes as simple beam structures, suggesting that chains would be unnecessary. A one-sixth scale model of one of the tubes was tested to destruction before the eventual design was arrived at and construction of the Menai bridge and its smaller neighbour at Conway (107/SH 787776) could begin. Conway was built first as the

tubes were smaller and only had to be raised some 18ft. It proved a useful trial run for the larger-scale and much more hazardous operation at Menai. Both bridges consisted of a pair of parallel tubes, each containing a single track. At Menai Stephenson was able to avoid heavy underwater engineering by siting the central pier on the Britannia rock in the middle of the Straits. By early 1846 the working drawings for the piers were well advanced, at a period when Stephenson was still considering the use of chains. The piers, were, in fact, built considerably higher than the level of the tubes and the holes through their tops for the chains that were never used are a feature of the bridge today. As at Conway, the tubes were built on shore and floated into position, hydraulic rams being used to elevate them. When all were raised, they were riveted end to end to form a pair of continuous beams, 1,511ft long, Stephenson himself driving the last rivet on 5 March 1850, so completing the world's longest span bridge at that time and also, at £600,000, the most costly. The bridge carried main line traffic to and from Holyhead until July 1970, when a fire in wooden staging inside the tubes resulted in their distortion beyond all hope of repair. Today a steel-arch structure sits, far from happily, between the piers, and the most important single monument of wrought-iron bridge building and early structural theory in the world is gone. Conway still survives, however, and, although strengthened with intermediate piers near each end, illustrates the constructional technique, but it has neither the dimensions nor the grandeur of the great Menai Bridge.

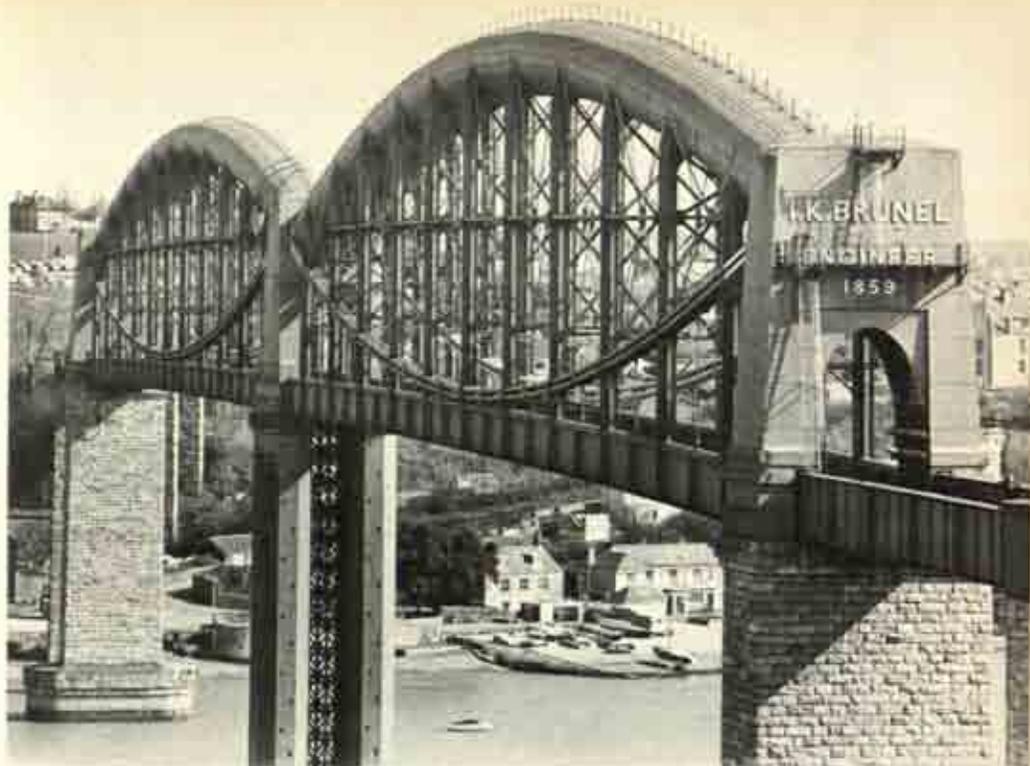
Slightly later in the 1850s wrought iron was used for an ingenious railway bridge designed by I. K. Brunel to carry the line of the South Wales Railway over the Wye at Chepstow (156/ST 539941). The two parallel main spans, of 300ft, consisted of plate girders supported by chains from piers at each end, but instead of carrying the chains back to an anchor point on the ground, Brunel held the piers apart by wrought-iron tubes 8ft in diameter. The tubes could not support themselves over this distance, so they were in turn supported from the bridge deck by wrought-iron A frames. Brunel's Chepstow Bridge was replaced by the present lattice steel structure in 1962, but the much more sophisticated design which derived from it still carries the old Great Western main line across the Tamar from Devon into Cornwall.

The River Tamar represented the most formidable obstacle to the westward progress of the Cornwall Railway from Plymouth and, as at

Menai, the exacting Admiralty stipulations about clearance for heights for slipping had to be met to the letter. Brunel was faced at Saltash with the problem of bridging 1,000ft of tidal water at a height of 100ft. The design eventually decided upon owed something to Chepstow, but here the tubes were elliptical in section, arched in profile and self-supporting. Besides withstanding the inward pull of the suspension chains, they shared with the chains the load of the bridge deck. Each of the spans is of 445ft, the composite truss, consisting of tube, catenary chains, suspender rods and deck, being 70ft deep at its centre and containing 1,600 tons of wrought iron.

The problem of the central pier was solved by using a 37ft diameter cylinder or caisson—the 'Great Cylinder', weighing about 300 tons—which was lowered vertically through the water and mud to rest on the bed rock of the estuary floor. The whole end of the cylinder was sealed off by the use of an airtight bulkhead, and in this pressurised space the foundations of the masonry pier were built. This was the first example of the use of a pressurised caisson for underwater work. Saltash Bridge (Plate 91) was opened to traffic by Prince Albert on 2 May 1859 but by then Brunel, who had gone abroad for his health before the second span had been raised, was within a few months of death. He returned to cross his bridge on a couch placed on a flat truck. Four months later he died and the inscriptions on the piers of Saltash Bridge, 'I. K. BRUNEL - ENGINEER - 1859', were placed there in his memory by the grateful directors of the Cornwall Railway.

By the 1860s wrought-iron bridges were becoming numerous. In the main they utilised fabricated plate 'I' section girders for small spans and lattice girders over greater distances. A fine example of a large wrought-iron girder bridge is to be seen at Runcorn (100/SJ 509835), where the L & NWR main line to Liverpool crosses the Mersey (and the later Manchester Ship Canal) on three 305ft spans. The bridge was completed in 1863. At Charing Cross a nine-span wrought-iron lattice girder bridge designed by Sir John Hawkshaw was opened in the following year on the site of Brunel's Hungerford suspension footbridge, which had been acquired by the South Eastern Railway and demolished. In later years Charing Cross Bridge was widened to carry three further tracks. Wrought-iron, sometimes in combination with cast iron, was also used for a series of remarkable and elegant lattice girder viaducts that crossed steep valleys at high level. The first of them, built at



91 Brunel's Royal Albert Bridge, Saltash, spanning the Tamar between Devon and Cornwall

Crumlin, Monmouthshire, in 1857, had ten 150ft spans in the form of lattice beams known as Warren triangular girders after Captain James Warren, who, with W. T. Manzoni, patented the system in 1848. The essence of the design is that no members in the girders are subjected to bending stresses, only to simple tension and compression. The piers were made of cast-iron columns braced laterally and diagonally with wrought-iron rods, giving the whole viaduct a delicate and ethereal quality which belied its strength. Crumlin Viaduct has been dismantled, as have two of basically similar design built in 1859 at Belah, Westmorland, and Deepdale, County Durham. Only Meldon Viaduct in Devon (175/SX 565924), built by the London & South Western Railway and completed in 1874, survives as a representative of the lattice girder and pier type of construction.

The final and in some respects greatest period of railway bridge building came very late in the evolution of the network and was part of a move to

shorten existing and often circuitous routes. The last barriers to direct railway communication were the great estuaries of the Tay, the Forth and the Severn, estuaries which were not to be tackled by the roadbuilders until nearly a century later. The first major railway bridge of this type was completed across the Tay in 1878, and in the following year, as a result of design and construction faults, was swept away in a gale with the loss of seventy-five lives. It was a wrought-iron lattice girder structure like its successor which stands today, the last of the great wrought-iron bridges and, with a total length of 10,711 ft, the longest railway bridge in Britain. The present bridge was designed by W. H. Barlow and opened on 20 June 1887. Beside it can still be seen the stumps of the piers of Bouch's narrow and spindly creation. The second Tay Bridge was the first civil engineering work in Britain in which an effort was made to calculate and allow for lateral wind pressure. It was designed to resist 56 lb per sq ft, giving a generous margin of safety and resulting in a rather solid and ungraceful structure. The next estuary to be tackled was the Severn, which was crossed in two places. The first crossing was completed in 1879 near Sharpness with a wrought-iron bowstring girder bridge, 4,161 ft long and carrying a single track. It was hardly a trunk route bridge, however, being designed mainly to give access to the Forest of Dean coalfield, and after being struck and badly damaged by a barge in 1960, it was subsequently demolished. The main crossing of the Severn came much lower down the estuary in the form of Britain's longest tunnel, opened in the 1880s.

The bridging of the Firth of Forth was the grand finale for the nineteenth-century bridge builders. It was the largest cantilever bridge in the world when opened in March 1890, and the first large civil engineering structure to be built in mild steel instead of the traditional wrought iron. The scheme to bridge the Forth started in earnest in 1873 when the Forth Bridge Company, a consortium of the North British, Midland, and Great Northern railways, was formed. Thomas Bouch, designer of the first Tay Bridge was appointed engineer and work had already started on an enormous suspension bridge when the Tay disaster occurred. Work on the Forth Bridge came to a standstill, the suspension bridge scheme was dropped and two new engineers, Benjamin Baker and John Fowler, were appointed in place of Bouch. In 1882 the contract was let for a cantilever bridge based on three towers made of 12 ft diameter steel tubes rising 361 ft above high water. From each tower

the lattice-braced cantilevers stretch out towards those of the next tower, the connection being made by two suspended lattice girder spans. Approach spans at each end are of conventional lattice girders on tapered granite piers. The central tower stands on the little island of Inch Garvie but the other two have concrete bases built in caissons; wrought-iron caissons 70ft in diameter were in fact sunk into the clay bed of the Firth under each of the four tubes of the towers. The Forth Bridge has a total length of 8,296ft.

In addition to the main types there were a number of minor types of railway bridge in Great Britain. Some were quite numerous but have now gone, like Brunel's timber viaducts in Devon and Cornwall, of which only the masonry piers can be seen here and there. Wooden viaducts still run across the Mawddach estuary south of Barmouth (116/SH 624150) and further north on the same line at Penrhyndeudraeth (116/SH 619384). Cast iron, too, was used as a bridge-building material surprisingly late in the railway age. At Ironbridge, Shropshire, the Albert Edward Bridge of 1863 is still in use (118/SJ 661038); it was designed by John Fowler, later of Forth Bridge fame, and cast by the nearby Coalbrookdale Company. In Derby an even later cast-iron arch, of 1878, crosses Friargate (121/SK 347364). Built by the Great Northern Railway, it was cast in the Derby foundry of Andrew Handyside, and exhibits *par excellence* the decorative possibilities of cast iron; the parapet panels and spandrels are full of floral ornament and also display the town's coat of arms, all cast in relief.

The large number of viaducts on British railways reflects the need for well graded, direct routes across undulating country, the same factors that resulted in so many tunnels. In towns, too, viaducts and tunnels are numerous, the obvious answers to high land costs. Paradoxically, tunnels in particular are nowhere near as common on lines in the mountainous areas of Wales and Scotland, where the economic incentive for a direct route was usually low and the topography so severe that circuitous valley-located routes involving minimum engineering works and therefore minimum expenditure were the norm. It must be remembered too that many of the lines in Wales and Scotland were built late in the railway era after the first flush of extravagance had died away. Thus there is only one tunnel in Wales over a miles long, at Blaenau Ffestiniog (107/SH 687505 to 697469), and there are none at all in Scotland. Britain's major railway tunnels are therefore concentrated in the Pennines and lowland England, cutting through what in many

places appear to be insignificant hills. Kilsby Tunnel through the Northamptonshire uplands has already been mentioned as an example of a shallow depth bore made necessary by Stephenson's stringent gradient requirements. Another early Stephenson tunnel, the first railway tunnel in the world over a mile in length, is at Glenfield in Leicestershire (121/SK 545065 to 561061) on the Leicester & Swannington Railway, opened in 1832. Its narrow single-track bore is now closed. Quite unavoidable, however, was the tunnel under the Pennines at Woodhead (102/SK 114999 to SE 156023) between Manchester and Sheffield, completed in 1845 after a 7 year saga of death and disease in the workings and the shanty navy encampments on Pikenaze Moor above. Built initially for a single track, it was later duplicated, and then in the 1950s replaced altogether by a modern double track tunnel put in to accommodate the 1,500V DC electrification scheme initiated by the London & North Eastern Railway. The stark portals can be seen, however, and one of the bores is now doing useful work carrying a power line that would otherwise have necessitated unsightly pylons across the moors.

To the industrial archaeologist the most obvious evidence of tunnels is their portals and, on the longer bores, their ventilating shafts. Unlike the canal builders the railway engineers used tunnels as an excuse for architectural extravagance, of which numerous examples can still be seen. The south portal of Primrose Hill Tunnel (160/TQ 276843) on the London & Birmingham 1½ miles out of Euston is Italianate in style, while at Shugborough in Staffordshire (119/SJ 982216 to 988216) one end of the tunnel is castellated and the other Egyptianesque. In the latter case the cosmetic architectural treatment, like that of the adjacent bridges, was required by the Earl of Lichfield, owner of the estate through which the line passed. Two other 'fortified' portals are to be found at Redhill (121/SK 496308) on the Midland main line between Leicester and Derby and at Grosmont (86/NZ 829051) on the abandoned alignment of Stephenson's Whitby & Pickering Railway. At Bramhope, Yorkshire, the 2 mile tunnel on the Harrogate line has an ornate castellated north portal (96/SE 256438) which is reproduced on a smaller scale at nearby Otley Churchyard (96/SE 202455) as a memorial to the men killed during its construction.

Britain's longest railway tunnel came late in the railway era and, like the longest bridges, spanned an estuary. From the 1850s the mouth of the Severn had been an obstacle to rail traffic between South Wales and London,

which had to travel via Gloucester. In 1863 the first attempt at a shorter route was completed with the opening of the Bristol & South Wales Union Railway to New Passage (155/ST 544864) and a ferry connection to Port-skewett and the South Wales Railway. Little remains of this venture today other than the stone landward section of the original timber pier and the flourishing New Passage Hotel. At Blackrock on the Monmouthshire side (155/ST 514881) two bridges and an overgrown cutting are all that remain of the connection with the main line. A tunnel as the final answer to crossing the Severn by rail was devised as early as the 1860s, taken up by the Great Western Railway in 1872, and eventually completed in 1886 at a cost of more than £1½ million. The Severn Tunnel when completed represented the ultimate in the engineers' fight against adversity. A natural freshwater stream, the Great Spring, was broken into and the workings were flooded by the river, delaying operations for about 3 years. The Great Spring has had to be pumped ever since, initially by steam engines and now by electricity. At Sudbrook (155/ST 507874) the huge 29ft shaft through which most of the Great Spring water is pumped can still be seen, but the six superb 70in Cornish beam pumps have been scrapped.

The design of passenger railway stations presented engineers and architects with considerable problems, for they were working in a field where no precedents existed. The logistics of handling large numbers of people arriving and departing simultaneously represented something completely new, and demanded a particular type of building combining all the basic functions in a logical and well articulated way. Thus the *layout* of stations is peculiar to the nature of railways themselves and represents a response to a specific challenge. In architectural terms, however, the designers of railway stations exhibited less originality, and, although the great roofs of termini were undoubtedly allied closely to the function of the station, the treatment of façades, of booking office blocks and of railway hotels was frequently pedestrian and derivative in the extreme. On the other hand the railway companies were responsible for some very good architecture both in large city stations and simpler rural surroundings. Railway architecture has become a study in itself and railway buildings, which often reflected the relative wealth and desire for prestige of their owners, illustrate in microcosm many of the essentials of Victorian architectural thought. As we have seen, the first railways required little in the way of buildings, but as early as 1830 the

termini of the Liverpool & Manchester Railway, of which the Manchester one still survives, had the essentials of booking office, waiting rooms and a sheltered platform for the passengers. By the late 1830s the U-shaped terminus station that was to become the standard had evolved, with arrival and departure platforms linked by a cross platform containing the entrances, waiting rooms and offices. An early example, now demolished, was Nine Elms, designed by Sir William Tite. Brunel's Temple Meads, Bristol, is another, which happily still exists.

Most early termini had one arrival and one departure platform, often separated by a number of tracks on which empty rolling stock could be stored. As traffic increased, the area of sidings in the centre was reduced and further platforms added. This happened at King's Cross (160/TQ 303831), the London terminus of the Great Northern Railway, which was designed by Lewis Cubitt and opened in 1852. King's Cross is a classic terminus, its simple brick façade penetrated by the arches of the double train shed behind expressing so perfectly its 'arrival' and 'departure' functions. Cubitt's claim that the station would fulfil itself architecturally through 'the largeness of some of its features, its fitness for its purpose, and its characteristic expression of that purpose' is admirably demonstrated.

Much more typical in London and other major provincial termini has been the combination of the hotel with the station offices in the transverse section of the U, resulting in the train shed being completely obscured. Nowhere is the duality of function and treatment better demonstrated than at St Pancras (160/TQ 302829), the terminus built by the Midland Railway when it finally gained access to the capital in the late 1860s. Both components of the station are larger than life; the iron and glass train shed by W. H. Barlow and the Butterley Company is enormous, its span of 240ft then being the largest in the world, and in front Sir Gilbert Scott's romantic red brick Victorian Gothic hotel is, in its architect's words 'possibly too good for its purpose'! St Pancras is still, happily, an operating station dominating the Euston Road, the ultimate expression of Victorian confidence and the might of the railway.

Other London termini incorporating hotels are Paddington (where Philip Hardwick's building of 1854 is architecturally interesting as an early example of French Renaissance and Baroque influence in England), Charing Cross, Cannon Street, Liverpool Street and Marylebone. The last named,

where the hotel now provides the headquarters for the British Railways Board, shows a marked disparity in size between the huge hotel block and the miniature station behind it. Marylebone, the terminus of the last main line into London, was built in the late 1890s by the Manchester, Sheffield & Lincolnshire Railway, which, to celebrate its new-found status, changed its name to the Great Central Railway in 1897. Today Marylebone only handles suburban traffic, the main line to the north through Rugby, Leicester and Nottingham having gone after little more than 60 years of life.

Through stations presented peculiar problems of design, particularly when, as was often the case, the town lay on one side of the railway. It was considered undesirable for passengers to have to cross the lines, so there was sometimes just one long single platform for both up and down trains. At Reading and Slough Brunel built stations of this type, with up and down station buildings both on the south side of the line, and at Derby Francis Thompson did much the same along the street side of an immense 1,050ft long platform (121/SK 363355). Although there were clearly some advantages in this type of layout for the passengers, the operating difficulties were considerable, since trains had to cross each others' paths on entering and leaving the station. Only one survives today in operational form, at Cambridge (135/TL 462573), the GWR stations having been rebuilt, and those at Derby, Chester General, Huddersfield and Newcastle having been given extra platforms. Thompson's Chester station of 1848 (109/SJ 413669) still retains its great façade—over 1,000ft of vaguely Venetian symmetry in stone-faced brick punctuated by little towers. The awning was added later.

Almost every conceivable architectural style can be found somewhere in British railway stations. Initially classicism was favoured, as at Euston and Birmingham Curzon Street (131/SP 080871), and it later spread to Huddersfield (102/SE 144169), Monkwearmouth, Sunderland (78/NZ 396577) and, finest of all, Newcastle Central (78/NZ 245638). Huddersfield, by J. P. Pritchett, is an example of a station (Plate 92) planned to be balanced by the same architect's designs in other adjacent buildings, in this case the George Hotel and Lion Arcade in St George's Square. Similarly at Stoke-on-Trent (110/SJ 879456) R. A. Stent matched the second Stoke station with the neo-Jacobean North Stafford Hotel on the opposite side of the square, while in Ashby-de-la-Zouch, Leicestershire (121/SK 355163), the frontage of the beautiful little Grecian station of 1849 (now disused) was part of a grand



92 The newly cleaned façade of Huddersfield Station, designed by J. P. Pritchett

plan to develop a spa town. Perhaps the last purely classical station façade is that of the also disused Bath Green Park (166/SO 745647), built in the early 1870s as the terminus of the Midland's branch from Mangotsfield and the Somerset & Dorset Railway.

The Tudor style appears in Bristol Temple Meads and Shrewsbury (118/SJ 494129) but is exemplified in its purest form in the Carlisle Citadel station of 1847, designed by Sir William Tite and described as Britain's 'finest piece of railway architecture in the sixteenth century collegiate style'. 'Jacobean' stations are mainly small, as at Maldon, Essex (162/TL 853077), and Stone, Staffordshire (119/SJ 896346), although an unusually large railway building in this style is the old General Office of the Bristol & Exeter Railway beside the approach to Temple Meads station in Bristol (156/ST 596724), completed in 1854 to the designs of S. C. Fripp. The Italian idiom was used by Tite in the late 1830s on the London & Southampton Railway and the original Southampton terminus (180/SU 422109) survives intact (see also Gosport station, Plate 93). Campaniles in the same vein appeared in the pumping stations installed by Brunel on his 'atmospheric' railway along the south Devon coast, but only Starcross (176/SX 977819), dating from 1846, is in anything like complete condition.

From an architectural point of view the stations of cities and larger towns



93 Ruinous colonnade of William Tite's Gosport Station, Hampshire

must be considered in the context of the other public buildings, with which they often compare well. It is in small towns and villages, however, that railway architecture really comes into its own, and where stations and often other railway buildings most frequently reflect the characteristics of individual companies. Their variety is enormous, but careful observation of the works of a particular railway will soon reveal similarities of style and frequent use of standardised components. Indeed one of the major contributions made by the larger British railway companies was in the development of pre-fabricated buildings based on a range of standardised components. Thus throughout the territory of the Midland Railway, for example, from St Pancras to Carlisle and Lincoln to Avonmouth, one may find signal boxes, station waiting rooms, level crossing gates, platform lamps and awnings fitting into one style. The typical Midland signal box was of unit construction, comprising standard timber posts, beams and panels that could be built in any number of bays, depending on the number of signal and point levers in the frame. Waiting rooms, too, were of standard design and, although usually built of brick, included standard components such as doors, bargeboards and cast-iron window frames. It is in this field of what might be called

'vernacular railway architecture' that much interest lies, and where, as the result of the great reduction in the number of passenger stations over the last 10 years, considerable recording and preservation effort is needed. Fortunately railways have received the attentions of innumerable enthusiastic devotees anxious to record every detail of a particular system, and although their efforts have tended to be concentrated mainly on locomotives and rolling stock, other aspects of railway operations are receiving increasing attention.

The whole field of operational railway preservation is in itself a remarkable phenomenon, which has resulted in a number of lines being kept running after official closure and others being revived and brought back into use, sometimes after many years of complete dereliction. The first line in the country to be saved by enthusiast interests was the Talylyn Railway, which in 1951 had been brought to the point of closure by declining slate traffic and road competition. Built in 1865 to serve slate quarries at Bryn Eglwys, it was opened for goods in the same year and for passengers in 1866. Today the 2ft 3in gauge line, covering the 6½ miles from Wharf Station, Tywyn (127/SH 586005), to Abergynolwyn (127/SH 671064), carries over 130,000 passengers each season. Also at Tywyn is a narrow-gauge railway museum. Other operating narrow-gauge railways in Wales include the Festiniog, running from Porthmadog (116/SH 571384) to Dduallt; the Welshpool & Llanfair Light Railway, based at Llanfair Caerinon, Montgomeryshire (117/SJ 106068); and the Vale of Rheidol, British Rail's only steam-operated line, which runs from Aberystwyth (127/SN 585815) to Devil's Bridge (127/SN 738769). Also in Wales and unique in Britain is the Snowdon Mountain Railway, a 2ft 7½in gauge rack line that climbs from Llanberis (107/SH 583597) to a height of 3,493ft. It was opened in 1896 and operates with 0-4-2T inclined boiler locomotives of Swiss manufacture.

Standard-gauge preservation schemes are widespread throughout the country and vary enormously in their aims and methods of operation. Most are concerned primarily with running steam locomotives and, although ostensibly 'preservation societies', few go further than preserving locomotives and stock in original condition. Some, such as the Keighley & Worth Valley, based at Haworth (96/SE 035373) in the West Riding of Yorkshire, and the Bluebell Railway centred on Sheffield Park Station (183/TQ 404237) in Sussex, include locomotives and rolling stock painted in non-original liveries,

whilst others like the Dart Valley Railway at Buckfastleigh (188/SX 746663), Devon, and the Severn Valley at Bridgnorth (130/SO 715926), Shropshire, maintain locomotives and rolling stock in the colours of their old owners. It is perhaps a little regrettable that, despite all this wealth of interest in railway preservation, as yet no line has been retained as a living example of how it used to be operated, with appropriate locomotives, stock, signal and telegraph equipment and so on.

## 16 Ports and Shipping

THE Industrial Revolution in Britain needed good internal transport systems, but equally important was the provision of facilities for import and export. The 'workshop of the world' was dependent on trade, and by the middle of the nineteenth century over 40 per cent of the entire world output of traded manufactured goods were produced in Britain, through whose ports passed over a quarter of total international trade. Over 90 per cent of British exports were composed of manufactured goods, which comprised only 7 per cent of imports. At no other time has one country so dominated the world economy. First canals and then railways gave manufacturers access to the coast, where sophisticated ports developed to handle goods in and out. Capital at least equal to that absorbed by canals was invested in the construction of these ports, although it was spread over a longer period.

In 1700 British trade was concentrated very heavily on London, which handled over 80 per cent of the nation's imports, 70 per cent of her exports and no less than 86 per cent of her re-exports. Defoe remarked that London 'sucked the vitals of trade in this island to itself'. In 1700 also London opened its first 'wet dock' at Rotherhithe. Previously London, like all other ports, had been entirely tidal, with ships either tying up at wharves and lying on the bottom over low tide or mooring in the river and being loaded and unloaded by lighter. The Rotherhithe wet dock consisted of a basin with entrance locks through which ships could pass into an area of water at constant level. There cargoes could be transferred safely and quickly between ship and shore. In Bristol, Britain's second port after London, ships made their way laboriously up the River Avon to the wharves of the city, where they lay on the bottom over low water. Bristol's exceptional tidal range, which is 42ft at Portishead near the mouth of the river, meant that a ship in port would be grounded twice a day, and vessels trading regularly with the city had to have specially strengthened hulls.

It could take as long as 4 months to turn a ship round in Bristol, and many had their backs broken while they were there. In 1712 a wet dock was completed lower down the Avon at Sea Mills (155/ST 550760) and, although long disused, substantial evidence of it can still be seen in the form of a masonry

wall and entrance lock. Sea Mills never became a real competitor to Bristol itself, being too far away from the commercial centre, and eventually it was used only by whaling ships, whose unwholesome cargoes were not welcome in the city.

The new trading activity of the eighteenth century, much of it transoceanic, led to rapid growth in other west coast ports. This growth was most dramatic in Liverpool. Defoe in 1720 thought its expansion 'one of the wonders of Britain . . . what it may grow to in time I know not'. At the end of the sixteenth century there had been fewer than 200 houses there and the Dee estuary, with Chester at its head, took prominence over the Mersey. By 1700 Liverpool's population was between 5,000 and 7,000, but it had reached 10,000 by 1720 and 30,000 by 1750—and canals had not yet connected the town with the heart of industrial England. Bristol also doubled its population in the first half of the eighteenth century, reaching 90,000 by 1750, but then growth slackened as the port lost ground first to Liverpool and then Glasgow. Liverpool's first wet dock was completed in 1715 and a further six were added in the succeeding century.

In Glasgow improvements in the Clyde were made by John Golborne between 1773 and 1781 and by the Clyde Trust after 1809; and on the east coast Hull, with its Baltic trade and close waterway connections with the West Riding, had formed a dock company by 1774 and opened three inter-connected docks by 1829. Completely new ports were also created, often for specific purposes, such as coal shipment. Seaham (85/NZ 435495) was the creation of the Marquess of Londonderry, who had coal interests in County Durham. On the west coast Maryport (82/NY 030365) in Cumberland developed for similar reasons.

Other new ports were canal-inspired, like Grangemouth (61/NS 925825), opened in 1777, at the eastern end of the Forth & Clyde Canal, or Goole (98/SE 745230), opened in 1826 at the Humber end of the Aire & Calder Navigation.

Between 1753 and 1830 some 370 acres of wet docks were provided in England alone. Harbour commissioners or trustees were formed at numerous places round the coast to put port finance on a firmer basis and carry out improvements in response to the growth of trade. They engaged outstanding civil engineers to advise them, including such illustrious names as John Smeaton (1724-92) and John Rennie (1761-1821). Rennie alone was involved

in over seventy harbour schemes. Not surprisingly the struggle with the sea to provide safe harbourage for ships led to many technological discoveries, including steam dredging, hollow walls and the diving bell. Although the cost of improvements was enormous, most of them enjoyed a much longer life than other works of the period, particularly the canals, which were soon to be ruined by railways. Their long-term usefulness, coupled frequently with very high standards of workmanship and materials, have meant that large numbers of port installations have survived to the present. As yet relatively little work has been done on the industrial archaeology of ports, which, with today's rapid rate of change in shipping techniques and increase in vessel sizes, are likely to undergo radical alterations in the next few years. The closure of Bristol's city docks in favour of concentrating traffic at Avonmouth can only be a few years away, and in Liverpool plans are already in hand to shut down all docks south of the Pier Head.

As an example of a port complex now almost completely extinct but offering much of interest to the industrial archaeologist, the estuary of the Lune in Lancashire is worthy of examination. Before the late seventeenth century the port of Lancaster confined itself mainly to coastal trade, but shortly after 1700 the opportunity was taken of widening its scope to include the West Indies. Warehouses were built in large numbers along St George's Quay (94/SD 474623), and several of mid-eighteenth century date still survive, their gable walls complete with wooden beam cranes or 'lucams', which were used for hoisting goods to upper floors. Some merchants built dwelling houses, of which several remain, but the most notable reflection of Lancaster's importance as a port in the eighteenth century is the fine Custom House, erected in 1764 to the design of Richard Gillow. A number of streets running back from the quay area to Cable Street were laid out around 1800, with names like Antigua Street, Barbadoes Street and Jamaica Street, but these have long gone, swept away by the railway in 1849.

Also in the early eighteenth century Sunderland Point (94/SD 426560), which lies between the Lune estuary and Morecambe Bay, was promoted as an outpost for Lancaster by Robert Lawson, a prominent local merchant. Here ships too big to make the difficult passage up to Lancaster itself could moor; a jetty was built and moderate prosperity enjoyed for a few years. The village is little changed today, with its two terraces of houses accessible

from Overton by a causeway submerged by the tide twice daily. According to legend the first bale of cotton to reach Lancashire was landed at Sunderland Point, to begin the industry for which the county was to become most famous. Across the river from Sunderland Point was Glasson (94/SD 445562), a safer anchorage, which soon took over as the unloading point for cargoes that were then shipped by lighter to Lancaster. In 1751 the port commissioners placed a chain and mooring stone there, and in 1791 a wet dock large enough to accommodate twenty-five merchant ships was completed. In 1826 Glasson Dock was linked with the Lancaster Canal, which necessitated the construction of a large inner basin. In 1834 a patent slip was laid down, in 1836 a grid-iron or frame on which ships could be repaired at low water was put in, and in 1838 a graving dock was opened. Today Glasson is the home only of pleasure craft and the odd surviving Morecambe Bay prawn boats or 'nobbies', the graving dock filling with rubbish, and the fine five-storey warehouse demolished for car parking. Yet the place has an air of former glory, and, like Lancaster itself, exudes the atmosphere of a once important port.

There is little remaining today in Bristol docks of eighteenth-century date with the possible exception of one or two small warehouses at the south end of Broad Quay. The whole harbour, which was tidal until the early nineteenth century, was completely remodelled by William Jessop, who installed an entrance basin—Cumberland Basin (156/ST 570723)—with lock gates, and in effect created a huge wet dock occupying the whole of the bed of the River Avon and its tributary the Frome for over a mile upstream. River water was diverted down a new specially excavated channel, the New Cut. These enormous works were completed in 1809 and for a time enabled Bristol to compete with the up-and-coming Liverpool. As the size of ships increased, however, problems of access along the tortuous Avon arose, and Jessop's entrance locks were soon found to be too small. I. K. Brunel, who had recently brought the Great Western Railway into the city, was called in by the Bristol Dock Company to carry out improvements, which he completed in 1848. A new south entrance lock (156/ST 570723), whose chamber can still be seen, was built for Cumberland Basin, and improvements made to the dredging system by the use of a steam-powered cable-hauled scraper. The engine of this boat is preserved in Bristol City Museum, where there is also a model of the complete vessel. By the 1860s

problems of increased shipping sizes arose again and the Port of Bristol Authority, the then municipal owners of the docks, undertook to build a new and larger north entrance lock, which is in use today.

Bristol city docks are still in use and contain a wealth of material of relevance to the industrial archaeologist. Their life cannot be long, however, as the newer docks built after 1877 at the confluence of the Avon with the Bristol Channel—Avonmouth and the smaller Portishead (1879)—have for nearly a century been the focal points of Bristol's port activities. At the entrance to Cumberland Basin in the shadow of a modern road swing-bridge is a grid-iron, installed in 1884 for the repair of small vessels, while over the entrance lock and Brunel's now redundant lock of the 1840s are two wrought-iron girder swing bridges. The first of these, dating from 1848, was installed by Brunel and is thought to be the earliest wrought-iron girder bridge in existence, if not the first ever constructed. The second bridge, built over the new entrance lock in the 1870s, is almost identical.

Like many ports in the nineteenth century Bristol used, and to a small extent still uses, hydraulic power to drive the numerous ancillary installations like lock gates, capstans and cranes. The hydraulic press, consisting of a small hand pump and reservoir connected to a hydraulic cylinder and ram, had been patented in 1795 by Joseph Bramah and was soon to be widely adopted for engineering work and, as modified by Matthew Murray (1765-1826) of Leeds, for baling cloth. In 1812 Bramah proposed the installation of hydraulic power mains on a municipal basis, with a central generating station and users paying by meter for the power they used. Although this far-sighted idea was not adopted for a further 65 years, it was in essence the basis for numerous dock installations. Both Bramah and Murray developed hydraulic cranes but it was the work of William (later Sir William) George Armstrong (1810-1900), whose first hydraulic crane was erected in Newcastle in 1846, that made hydraulic power widely acceptable both in docks and elsewhere. Armstrong devised the weight-loaded hydraulic accumulator to provide sufficient head, air vessels to balance the fluctuations between supply and demand and smooth out pump pulsations, and the hydraulic jigger (consisting of a jack with pulley sheaves mounted at each end) by means of which the effective stroke could be multiplied and excessively long jack cylinders obviated.

The first public hydraulic supply was installed in Hull in 1877, to be

followed in London by the installations of the Wharves & Warehouses Steam Power & Hydraulic Pressure Company, which in 1883 operated some 7 miles of mains on both sides of the Thames. In the following year this company was absorbed into the London Hydraulic Power Company, which by the 1930s supplied over 8,000 separate hydraulic machines through 184 miles of mains. About half this number of machines are at present supplied. Elsewhere many of the large public hydraulic-power companies have closed, in Hull because of war damage, and in Liverpool as recently as 1970 as the result of a dwindling consumer demand. The Glasgow and Manchester systems have also closed down recently. (An electrically powered hydraulic generator pump is on display, working in the local history gallery of the City of Liverpool Museums.)

By the standards of these installations, that at Bristol is small, supplying power only for the port authority's own use. The generating station is near the Cumberland Basin at the Underfall Yard (156/ST 572722), where there are three electrically driven pumps by Fullerton, Hodgart & Barclay of Paisley. A brick accumulator tower near the generating station is no longer used, but outside is a modern steel tower where the weight can be seen falling and rising intermittently as water is taken from the mains and then replenished. The system is used regularly for the older swing bridges of Cumberland Basin and the lock gates. A few hydraulic cranes may still be seen in the city docks, but they are now out of use. Prince's Street Bridge (156/ST 586723), although not now hydraulically powered, also has a small booster accumulator tower.

Numerous examples of hydraulically operated machinery can still be seen in most ports of any size, the accumulator tower usually being the most obvious clue to their existence. Of these, the campanile-style tower standing between the entrance locks at Grimsby (105/TA 281113), Lincolnshire, must be the most spectacular. Dating from the early 1850s, it is 313ft high and was built by the Manchester, Sheffield & Lincolnshire Railway to provide a head for the hydraulic mains of the port and support a freshwater tank for ships. It is not an accumulator tower in the true sense of the term, but an artificial head of water for the hydraulic mains, consisting of a 33,000 gallon tank into which water was pumped by a steam engine. The enormous cost of providing a tower like that at Grimsby was instrumental in the development of the accumulator proper, in which a large weight is

raised on a piston to create the same sort of pressure. The Grimsby tower now serves only as a television relay station and for supplying water to wash down the fish pontoon. Other towers may be seen in Liverpool docks and at Glasgow.

Numerous bridges are still powered by hydraulics, including the famous swing bridge across the Tyne at Newcastle (78/NZ 253637) built by Armstrong in 1876, and several swing bridges on the Manchester Ship Canal, including the Barton Aqueduct and the adjacent road bridge (101/SJ 766976). The best known of all, Tower Bridge, London (160/TQ 337802), an engineering masterpiece and architectural absurdity to the designs of Horace Jones, architect to the City of London, and John Wolfe Barry, was opened in 1894. Construction was by William Arrol, with hydraulic equipment supplied by Armstrong's of Newcastle. There are four hydraulic engines to each 1,070 ton bascule leaf, and in ordinary working only one engine to each leaf is used, the other six engines being in gear and running idle with water circulating through their cylinders and valves. The four accumulators were until recently charged by a pair of double-tandem-compound steam engines, each of 360hp, but these are now out of use and hydraulic supply is drawn from the London Hydraulic Power Company's mains. Each tower also has hydraulic lifts giving public access to the high-level pedestrian deck. Visitors may at present see all this equipment by appointment, but eventually electric power may be installed or the bridge itself demolished in favour of a fixed bridge of higher traffic capacity. The very improbability of this worldwide tourist attraction justifies its preservation; how appropriate that it should retain its hydraulic equipment rather than become still more of a sham, with electric motors or perhaps no power at all.

The growth of trade through British ports in the early years of the nineteenth century necessitated a completely new approach to the provision of port installations, particularly warehousing (Plate 94). Traditionally quayside warehouses had been relatively small, of up to four storeys, and with timber floors supported on timber beams presenting problems of load capacity and fire risk. The warehouses in Lancaster, already mentioned, typify what might be called the 'pre-industrial' warehouse building. Other examples may be seen in ports as far apart as King's Lynn, Norfolk; Boston, Lincolnshire (Plate 95); Bideford and Exeter in Devon (where appropriately



94 Mid-nineteenth-century warehouses at Gloucester Docks

95 Late eighteenth-century warehouses at Boston, Lincolnshire



some warehouse buildings form part of a developing and wide-ranging maritime museum). One of the King's Lynn buildings, incidentally, on Nelson Street overlooking Mill Fleet, provides a fine example of a new use for an old industrial building, for here the granaries have been sensitively converted into offices. In Portsoy, Banffshire (30/NJ 589665) a group of miscellaneous harbour buildings have been converted into council houses.

Bristol also has a number of early warehouses of traditional construction, alongside others which represent the transition to a larger scale of port building that developed mainly in London and Liverpool. One of these transitional warehouses is J. & R. Bush's tea bond on Prince Street (156/ST 586725), overlooking the traditional heart of the city's harbour at the junction of the Avon and Frome. Dating from the 1830s, it is a five-storey structure with timber floors supported by cast-iron columns. The boldly featured stone exterior, with its prominent string courses and arch-headed windows, heralded a more exotic style of Bristol warehouse that developed after 1850, but in terms of constructional technique nothing more advanced was built in the port until the great tobacco bonds of the early 1900s. The city docks continued to be provided with relatively small warehouses, appropriate to the size of ships trading there, of which a few classic examples survive. Two beside Bathurst Basin (156/ST 587722) exhibit in a restrained way the polychrome brickwork and ogee arches which typified large numbers of buildings in the Victoria Street area in the third quarter of the nineteenth century, a style which has since become known, with some architectural inexactitude, as 'Bristol Byzantine'. The prize example of the style is on Welsh Back (156/ST 588726), built in 1869 to the designs of two local architects, Archibald Ponton and W. V. Gough. It epitomises Bristol Byzantine at its most exotic and yet, despite its unusual outside appearance, the internal structure is of conventional timber joists and floorboards. The building is now a jazz club.

London's early wet docks, like that at Rotherhithe, had no warehousing of their own—indeed the Rotherhithe Dock had a double row of poplar trees round the basin as a protection against wind. Similarly Brunswick Dock, Blackwall, opened in 1790, was chiefly intended for the safe accommodation of the East India Company's ships, and the only building of note was the masting house. Not until the opening of the West India docks in 1802 was a system of warehousing provided, solving at once two major problems—

the difficulty of unloading ships in tidal water and, by the provision of a Customs wall, the pilfering of cargoes, which had been causing merchants grave concern.

The origins of large-scale port warehousing may still be seen, in a somewhat diminished state, in St Katharine Dock, London. The purpose of the dock was to provide both an unloading place for ships and quayside warehousing as close as possible to the commercial heart of London. The St Katharine Dock Company Act was passed in 1825 for an enclosed wet dock system immediately to the east of the Tower of London (160/TQ 339805). Thomas Telford was chief engineer, with Philip Hardwick (1792-1870) as architect. The two major criteria which Telford and Hardwick had to apply in developing the 23-acre site were the need to obtain as much quayside length as possible for unloading purposes and the provision of the maximum amount of warehouse storage space. Room had also to be made for several vessels docking together as, unlike today, arrival times were very dependent on the weather. The final design consisted of two irregularly shaped docks each linked to a smaller entrance basin, although here the originally intended second entrance lock was never built. In having all its warehouses built up to the water's edge, St Katharine Dock was unique. Normal practice was to have an open quay, transit sheds and a road between the water and the warehouses. The idea at St Katharine's, however, was to save double handling by taking goods straight from the ship's hold to the appropriate floor of the warehouse by means of overhead cranes.

The result was a magnificent range of six-storey warehouses, cubelike, compact and functional, with a ground floor arcade of giant cast-iron Doric columns and full-height round-headed blank arches embracing the windows above. Most were designed by Thomas Telford but the block on the west side facing the Tower Bridge approach is by Hardwick. Architecturally their importance lies in the combination of utilitarian function and a classical discipline of design, and they represent an important stage in the development of buildings adapted specifically to the large-scale requirements of the nineteenth century. The constructional technique of the initial buildings was in fact fairly conventional, with timber floors, but the central block, added in the late 1850s, had an iron frame and stone slab floors. After suffering extensive bomb damage in 1940, after which several of the warehouses were demolished, St Katharine Dock was eventually closed in

October 1968 and the site is now the centre for an ambitious redevelopment scheme under the auspices of the Greater London Council which involves the retention of most of the surviving buildings and dock area.

Although London has always retained its lead as Britain's major port, the eighteenth and nineteenth centuries saw Liverpool take Bristol's place as the second most important, with Hull, Glasgow and at the end of the period, Manchester, all overtaking her also. Liverpool's small cluster of wet docks near what is now called the Pier Head formed the basis for the remarkable linear development of docks, now exceeding 7 miles in length which is illustrated in Fig 31. The evolution of this dock estate during the nineteenth century was influenced by a number of factors, including the need for more dock and warehouse space as traffic increased, the building of larger vessels, the coming of steamships, and the need for greater security, which led to the separation of the dock area from the city. In much of this development the central figure was Jesse Hartley, who was dock engineer from 1824 until his death in 1860 and whose indelible stamp still characterises much of Liverpool's dockland. This linear development and need for greater security was emphasised by the great wall that Hartley built on the landward side of the dock estate and alongside which the present Dock Road runs. Entrances were protected by huge sliding gates and towers that have all the appearance of miniature fortifications. Only Stanley Dock, opened in 1848, lies outside the wall, but this was because it formed the link between the main dock system and the Leeds & Liverpool Canal. By the time of Hartley's death the line of docks stretched from Canada Dock on the northern edge of Liverpool to Brunswick Dock in the south, the latter the first dock to be built by Hartley himself.

Undoubtedly Hartley's masterpiece is Albert Dock (100/SJ 342897), close to the traditional heart of the port and immediately south of the Pier Head. Albert Dock (Plate 96) is the logical extension of the principle established in St Katharine Dock, London, in the late 1820s, but here the rectangle of open water is surrounded by an almost complete wall of warehousing coming right up to the edge of the quay, although still retaining the arcade with cast-iron columns at ground floor level. The columns are modelled on Greek Doric prototypes and are hollow drums 12ft 6in in circumference and 15ft high. Encased with walls of brick, the five floors of the warehouses are supported on iron columns, the spaces between them spanned by cast-iron

# THE GROWTH OF THE LIVERPOOL DOCK SYSTEM 1760-1960

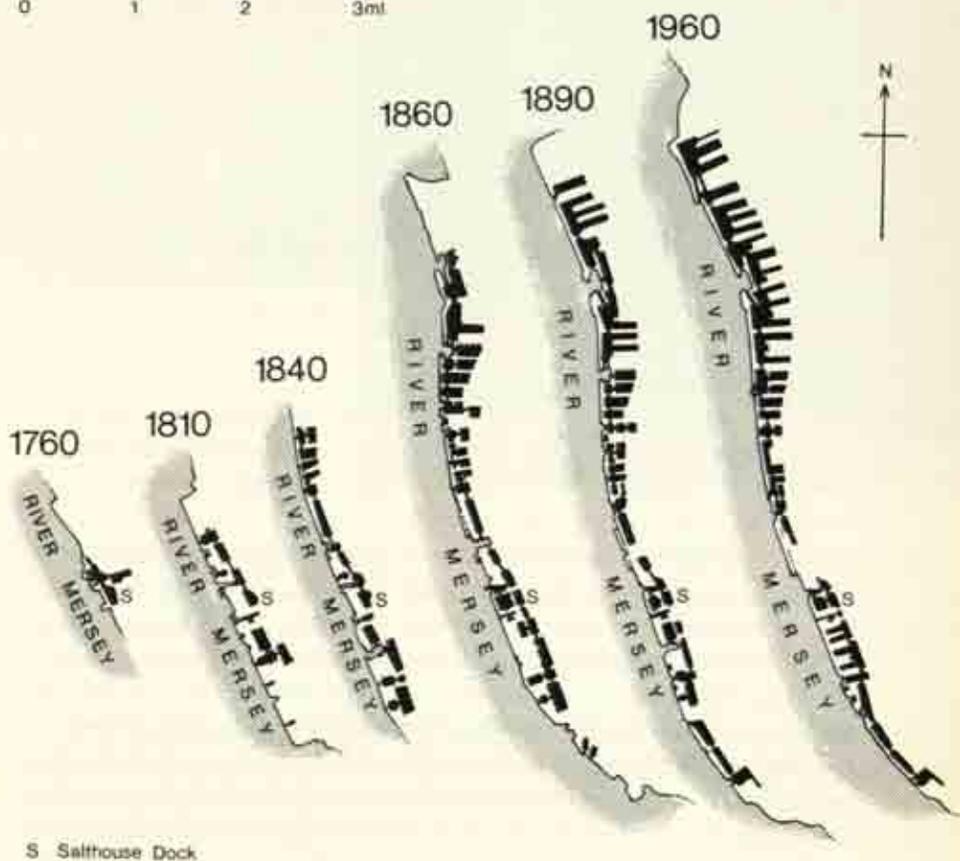
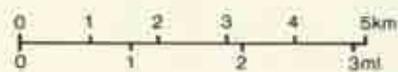


Fig 31



96 Albert Dock, Liverpool.  
Colonnade with cast-iron  
columns

beams of inverted-Y section tied laterally with wrought-iron tension rods. From these beams spring the brick arches of the floors (Plate 97), the whole method of construction evolving directly from the pioneer work of Strutt and Bage in Derbyshire and Shrewsbury at the end of the eighteenth century. At Albert Dock, however, even the roof trusses are of iron, and the roof itself is made of wrought-iron plates. Tucked into the north-east corner is the Dock Traffic Office, dating, like the warehouses, from the mid-1840s but in this case designed by Philip Hardwick, who had collaborated with Telford at St Katharine Dock and meanwhile built a triumphal arch at Euston. Hardwick's design for Euston seems to have influenced him in Liverpool, and the Tuscan portico of the Dock Traffic Office, entirely constructed in cast-iron, symbolises *par excellence* Victorian commercial achievement and self-confidence.



97 Albert Dock, Liverpool. Interior of warehouse showing cast-iron columns and beams with brick vaulting

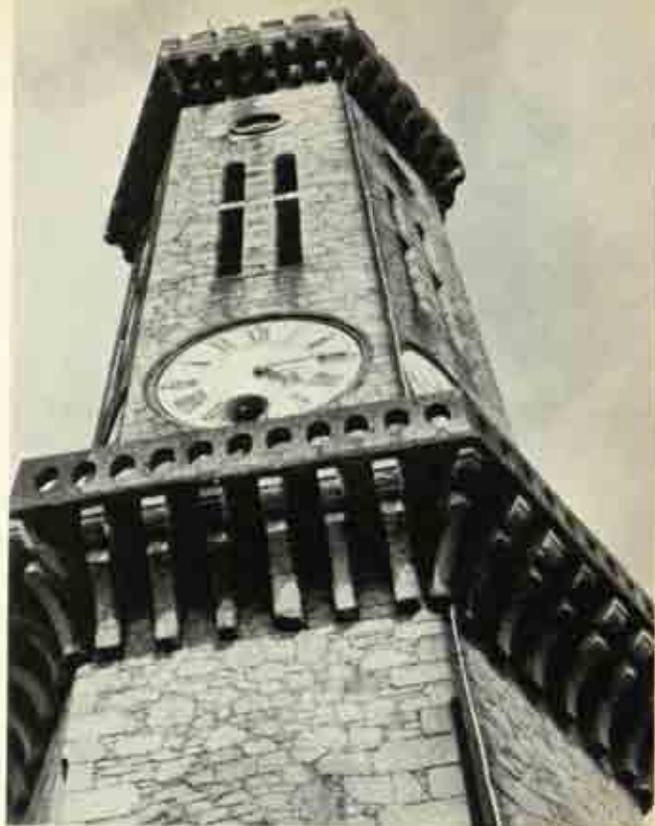
Granite, brick and iron are the materials for the monumental mass of the Albert Dock warehouses, the ultimate demonstration of the maritime prosperity of the Port of Liverpool. Today they stand disused, ships having outgrown the dock facilities, and multi-storey warehouses having lost their *raison d'être* in a world of containers and fork-lift trucks. Their colossal bulk rising above the Mersey Wall presents every planner or would-be conservationist with a problem, for while it is easy to save a watermill or even a reasonably sized railway station, the supreme monuments to Victorian industrial and commercial might have become commercial white elephants in areas of high land values. They are too big to retain and yet their retention is essential. They could be turned into maritime museums or a polytechnic—'Pierhead Poly' has been proposed—or into offices, small workshops, even residential accommodation. Perhaps a combination of all of these is the answer, but fundamental to achieving the right solution is the need for just a fraction of the spirit of adventure, confidence and imagination that gave birth to Albert Dock over 130 years ago. What J. A. Picton in 1875 described as 'a hideous pile of naked brickwork' in his *Memorials of Liverpool* can now

be appreciated as one of the supreme archaeological monuments to the rise of the first industrial nation.

Albert Dock, however, is not the only site of industrial archaeological significance in the Port of Liverpool. Whole areas of the city are rich in dockland archaeology. Within the estate are swing bridges, including cast-iron examples designed by Hartley at Albert, Salthouse and Wapping Docks, and a curious timber footbridge across the entrance to Canning Dock (100/SJ 342899), supposedly by John Rennie. Similarly the warehouses and transit sheds, particularly those of the Hartley era, are almost universally of a monumental scale and impeccable standard of construction. By contrast much of the private warehousing inland from the Dock Road is mean and penny-pinching. Despite the Liverpool Warehouse Act of 1843, which introduced reduced premiums for brick and iron structures, many were still built with timber floors up to the latter part of the nineteenth century. Other worthwhile sites include Hartley's Victoria Tower (100/SJ 333922), completed in 1848 at the entrance to Salisbury Dock (Plate 98) and the Floating Landing Stage (100/SJ 337904) at the Pier Head by G. Fosbery Lyster and Sir William Cubitt (1876). Victoria Tower, built of the same grey granite as his other dock works, is unmistakably Hartley, the stone blocks carefully dressed and fitted together like a jigsaw puzzle. It carries an unusual six-faced clock and bell to ring out warnings. The Landing Stage, on the other hand, is much more utilitarian. Built on iron pontoons and originally nearly  $\frac{1}{2}$  mile long, it was the place from which Liverpool's transatlantic liners departed—Cunard and White Star until they moved to Southampton, Canadian Pacific more recently. Now it is only used regularly by the ferries and the packet boats to the Isle of Man.

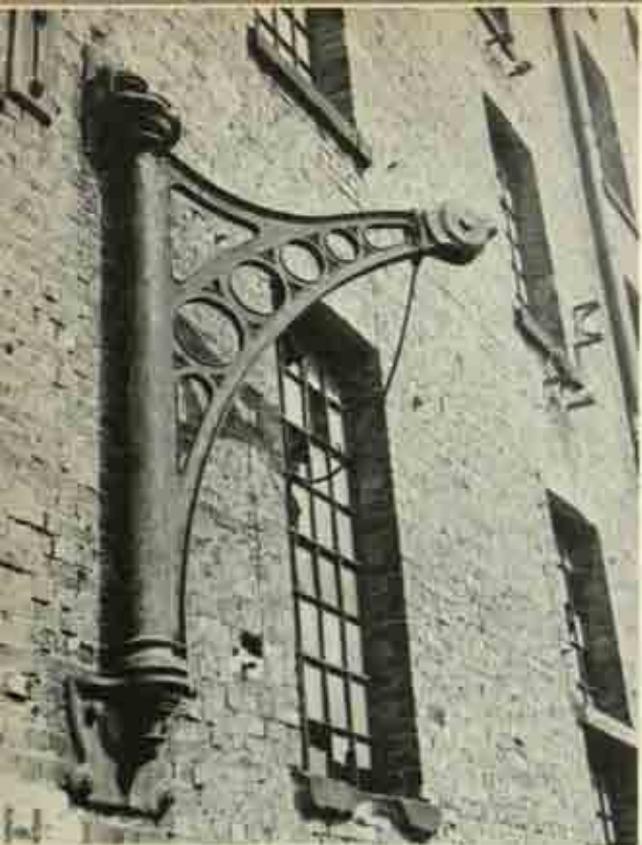
Unlike London, Liverpool had no other major function during the nineteenth century and first part of the twentieth than being a port, so the down-town part of the city, more so than any other in Britain, reflects a deep involvement with ships and commerce even today. Marine insurance offices, shipping company offices, dockside pubs, warehouses and merchants' houses are all still there, some still thriving but others in the final stages of decay. The Sailors' Home in Canning Place (100/SJ 345900), dating originally from the 1840s, came into this last category. Externally a fair representation of Hardwick Hall, its cast-iron inside closely resembled an American penitentiary. It has now been demolished. In a healthier state is

98 Victoria Tower, Liverpool Docks, built of the random granite blocks favoured by Jesse Hartley



the Albany (100/SJ 340906) on Old Hall Street, dating from 1858 and one of the finest of the Victorian office blocks that grew up immediately inland from the waterfront. It is built round a courtyard that is spanned by a delicate cast-iron bridge reached by a spiral staircase. The yard provides light to the inner offices, as do skylights above galleries at each side of the building.

The industrial archaeologist in dockland has unrivalled opportunities for the discovery of obscure and obsolete equipment in addition to the more obvious large-scale installations. Winches and hand cranes frequently bear makers' names cast into them, as do iron mooring bollards. Cranes alone (Plate 99) are worthy of detailed examination, as almost any which are not electrically powered may be regarded as obsolete. Harwich (150/TM 262325) has what is probably the oldest crane (Plate 100) in Britain, dated 1666; it consists of a fixed wooden house containing a treadmill and a swinging jib



99 Albert Dock, Liverpool.  
Cast-iron swinging-jib crane

100 Treadmill-powered seventeenth-century quayside crane preserved at Harwich, Essex



mounted on heavy framing at one end and turning through 180 degrees. It has been moved from its original site in the original harbour area. Steam cranes were introduced about the same time as Armstrong was experimenting with hydraulic power, but few of either type now survive. A heavy lift steam crane with riveted wrought-iron plate jib dating from the 1870s (156/ST 584722) can be seen in Bristol, and there is a smaller example in Dover. Electric cranes, introduced in the 1890s, are now almost universal, although the earlier types, like the one at Southampton dated 1893, are becoming increasingly scarce.

To enable ships to navigate coastal waters safely, lighthouses have been provided from ancient times, but it was not until the eighteenth century that there was any systematic approach to the design of either the tower or the light it carried. John Smeaton (1724-92), who built the third Eddystone Lighthouse 14 miles from Plymouth in 1759, was one of the first to examine the civil engineering problems, and his dovetailing of the core stones of the tower became a standard technique. Smeaton's light continued in use at the Eddystone until 1882, when it was decided to build a new tower on a different part of the reef because the foundation rock was becoming undermined. Smeaton's lighthouse was then re-erected on Plymouth Hoe (187/SX 478538), where it may still be visited. In 1836 Parliament transferred all English lighthouses to the care of Trinity House, while in Scotland the Commissioners for Northern Lighthouses, established in 1786, were responsible for a number of notable lights.

#### SHIPBUILDING

During the first century or more of industrialisation in Britain the nation's trade was handled by sailing ships that changed relatively little in design or size. Shipbuilding was an industry steeped in tradition and slow to respond to new requirements. It was no accident that Captain James Cook (1728-79) circumnavigated the world in what was basically a Whitby collier. This was the best type of vessel available to the British Admiralty, so it was used for the job. Towards the end of the eighteenth century came a gradual move to improve ship design led by the French, although later the North Americans took the lead in merchant shipbuilding. Despite conservatism of design and constructional techniques the British merchant fleet grew

enormously during the eighteenth century, the total tonnage rising from 323,000 tons in 1700 to reach the 1 million ton mark by 1788.

There were, however, improvements to individual parts of ships and to the techniques of constructing them. In the 1780s copper sheathing of the wooden hulls to prevent attack by the Tereido ship worm was introduced, while in the early 1800s Sir Marc Isambard Brunel, father of I. K. Brunel, designed mass-production machine tools for the manufacture of pulley blocks (see p186).

Although the first steam paddle boat to run commercially, the *Comet*, designed by Henry Bell (1767-1830), had indicated the potential of the new form of power as early as 1812 on the Clyde, it was some years before steam navigation had any real impact. In April 1838 the 703 ton *Sirius* made the first transatlantic crossing mainly by using its steam engine, beating by a few days the paddle steamer *Great Western*. Designed by I. K. Brunel, the *Great Western* was the first ship built specifically for the transatlantic trade. She was 236ft long and weighed 4,000 tons, but the hull was basically of traditional timber construction although heavily strengthened with iron knees and bolts. Not until the hulls of ships were built completely of iron could the potential of the steam engine be fully realised.

The first iron vessel had been launched into the River Severn at Preens Eddy below Ironbridge as early as 1787. Designed and built by the local ironmaster John Wilkinson (1728-1808), it was no more than a barge, probably of similar general appearance and constructional technique to the mid-nineteenth century iron tub boat preserved on the Shropshire Canal in the Blists-Hill Open Air Museum (119/SJ 694034). The demand of the steam engine prompted active investigation of the possibilities of iron hulls and this fact, coupled with the success of Brunel's *Great Western* in 1838, encouraged both her owners and designer to think on a completely new and unprecedented scale when planning their next ship. That ship was the *Great Britain*, the first screw-propelled all-iron merchant ship to enter Atlantic service. Designed by Brunel, she was the largest ship afloat when Prince Albert launched her in Bristol on 19 July 1843. Unlike most vessels then and now *Great Britain* was not built on a slipway but in a drydock that had been specially built to accommodate her enormous bulk. That dock still exists, holding once more the ship to which it gave birth (158/ST 578724). After a varied but successful career involving a number of alterations to engines and

rig, *Great Britain's* active life ended in 1886 when she was abandoned as a hulk in the Falkland Islands. Then, a century and a quarter after her launching, she was returned to Bristol showing signs of age but not of any major deterioration, a remarkable testimony to the skill and workmanship of her builders. The Great Britain Steamship Preservation Project, which raised the money to salvage the ship, is now actively engaged on her restoration, which visitors to Bristol are welcome to see.

Although the *Great Britain* in her dock is perhaps the most spectacular combination of maritime and shipbuilding archaeology to be found anywhere, there are numerous other remains of significance to the industrial archaeologist. Unfortunately shipbuilding tends to produce few lasting remains other than the ships themselves, and the adoption of prefabrication and welding techniques in an industry that since the 1920s has been in an almost perpetual state of flux and reorganisation has meant that there is often little of significance left to see. There is ample evidence of the products themselves, however, in the form of models in museums like Glasgow, Sunderland, Liverpool and Bristol, and in the Science Museum, South Kensington, the Maritime Museum at Exeter, and the National Maritime Museum, Greenwich. Other evidence is available in the form of plans and drafts, and in the records of Lloyd's.

Naval shipbuilding has left more to posterity than the merchant ship side of the industry. In addition to HMS *Victory* at Portsmouth and the cruiser *Belfast* in the Pool of London, efforts are now being made to preserve the hull of HMS *Warrior*, the first British armoured battleship, launched in 1860, and now part of an oil pipeline jetty at Pembroke. The Naval dockyards, too, are rich in important structures relating to both the building of ships and their subsequent operation. The four dockyards at Portsmouth, Chatham, Sheerness and Plymouth (Devonport) all contain an assortment of buildings of all periods from the seventeenth century onwards, including stores, docks, workshops, barracks, foundries, ropewalks, dwellings and chapels. Particularly important are the No 53 Boat Store at Chatham (172/TQ 765700), built in 1813 for building and repairing men-of-war; the cast- and wrought-iron framed boathouse of 1858 at Sheerness (172/TQ 910753); and the cast-iron framed fire station, previously a storehouse, at Portsmouth (180/SU 630005). The Sheerness boathouse is one of the earliest known multi-storey iron-frame buildings, and was designed by

Colonel G. T. Greene, Director of Engineering and Architectural Works at the Admiralty from 1850 to 1864. It is a frame building, i.e. the whole structure is supported by its frame, and the external walls are non-loadbearing panels of standardised form. Beams supporting the floors are fabricated from wrought-iron plate and angle riveted together to form H girders, the earliest known large building in Britain where this form of construction occurs. Since 1960 the Navy has stopped using Sheerness Dockyard, but at the others access may be obtained by special permission.

One remaining aspect of the industrial archaeology of ships and shipping is worthy of mention because it is a rapidly developing field offering some considerable possibilities for research. Submarine archaeology has forged ahead in recent years with the improvements made in self-contained diving apparatus, and although most of its practitioners have so far been largely concerned with wrecks, the possibilities for underwater surveying and recording in the industrial archaeological field are obvious. Recording and excavation underwater can be as accurate and thorough as on land, and the information recoverable from the 'closed site' of a well preserved wreck is often very great. The standards of surveying, recording and plotting of finds are at a relatively elementary stage in Britain, but the Committee for Nautical Archaeology, founded in 1964, is endeavouring to coordinate and systematise the approach to this new field of research and eliminate some of the regrettable unscientific exploration of sites that has occurred so far.

## 17 Conclusion

IN this review of the major industries an attempt has been made to link processes and the stages of their evolution with the surviving visual evidence. This has not always been possible, however, with the result that imbalances occur which in no way reflect the relative importance of various industrial activities. Thus the chemical industry, of enormous and generally unrecognised importance throughout the Industrial Revolution, has received less than its due because the physical remains, or at any rate the significant and comprehensible ones, have virtually disappeared. The present state of industrial archaeological knowledge, together with the variability of individual enthusiasms, contributes to this problem; canals and railways are more inspiring than lead-chamber sulphuric acid plants, even supposing any still exist. With the increasing amount of disciplined and well organised work within the field of industrial archaeological recording, however, these enthusiast imbalances are being redressed, particularly as local societies build up comprehensive surveys of the whole range of sites within their own areas.

Numerous industries have not been mentioned at all, but this does not mean to say that they have no archaeological significance. Food processing, clothing, and boot and shoe making are some of the areas which have been neglected but, in the case of the latter, a detailed analysis of the industry in and around Northampton will reveal through surviving buildings the transition from a domestic to a factory-based industry in the mid-nineteenth century. This change occurred to some extent as a result of the introduction of American-made sewing machines, initially for closing the uppers but later for sole and welt sewing. Examples can be seen in Northampton Museum. In the 'domestic' system the uppers were cut and stitched together (closed) at a central premises and then sent out to hand-sewers working usually in sheds at the bottom of their gardens. These 'shops' can still be seen in many Northamptonshire towns and villages. By the end of the nineteenth century the processes had all been gathered together into factories, with the cutting of the leather (clicking) and closing on the top floor where there was most light and the machines were not heavy, lasting and attaching on the floor below and at the bottom the leather stores and heavy cutting

presses. This simple functionalism, with the work flowing down through the building, still exists in some Northampton factories. Thus the physical evidence of buildings and to a lesser extent machines exists to illustrate the stages in the transition from a cottage industry to that ultimate in mid-nineteenth century shoe factories, the Manfield Building in Campbell Square, Northampton (133/SP 755609). To find out *why* shoes are made in Northampton requires evidence of a completely different type. Only a detailed analysis of documentary sources and a thorough appreciation of a range of geographical factors will build up the picture of coinciding elements—of cattle for leather, perhaps of oak trees providing bark for tanning, of agrarian unrest and unemployment associated with enclosure—creating the conditions for the growth of the industry. Northamptonshire tended at first to specialise in cheaper shoes, as the top end of the market was largely the province of London-based shoemakers located near their discerning customers. Northamptonshire shoemakers prospered on army contracts, initially for Cromwell's New Model Army, and eventually gaining a virtual monopoly of all service footwear. All this, but particularly the relation of the physical evidence to other sources, is the concern of the industrial archaeologist.

Besides the evidence of its own specific technology, the brewing industry affords the industrial archaeologist an opportunity to examine functionalism in building design and construction at its purest. In addition the appreciation of the role which many of the spectacular structural elements, particularly of maltings, play in both urban and rural landscapes is a refined aesthetic experience in its own right. Malting as an essential part of the brewing process has been carried on both at the brewery itself or in separate establishments. The process consists of encouraging barley to germinate and thereby change its starch content into sugar, at which stage the process is arrested in drying kilns. Before the development of large-scale breweries, malting was a local and very small-scale activity carried out in almost every town. Even so, some had marked concentrations of small maltings. Marshfield in Gloucestershire, for example, had dozens, and the characteristic perforated tiles from the drying floors are commonplace there.

The development of large-scale maltings, often separate from the breweries themselves, in the second half of the nineteenth century resulted in some of the most visually stimulating and dynamic examples of functional building to emerge during the Industrial Revolution. East Anglia and the Home

Counties, areas not noted for their high degree of industrialisation, are rich in these sophisticated and often beautiful buildings. The main part of the structure usually has three or more floors for the germination process, often with floor to ceiling heights of only 6ft or even less, with small rectangular windows louvered to serve as vents. Very typically there are tie irons passing through the building whose presence is evident on the exterior in the form of tie plates—huge crosses or discs of cast iron regularly spaced along the façades. Attached are the kilns with their tall pyramidal roofs and cowls. The architectural personality of these structures derives from the common ingredients of functional elements often combined with great size (Plate 101), so that they make their presence felt in the landscape in a very positive but honest and unobtrusive sort of way. Often, because of their rural situation, it is difficult to associate them with an industrial process at all; they are more an extension of the agricultural tradition of building.

Their extensive floor areas and attractive proportions have led to some highly successful conversions of disused maltings to new purposes. Best known are the Snape, Suffolk, maltings now a hall for the Aldeburgh Music Festival (137/TM 392575), while in Newmarket a much larger maltings is occupied by a colour-processing laboratory. The oasthouse in which hops are dried, also for brewing, is another distinctive structure common in Kent but also to be found in Worcestershire and Herefordshire.

101 Late nineteenth-century maltings at Ipswich Docks, Suffolk



Cylindrical kilns with their characteristic wind vane cowls are, generally speaking, older than the rectangular type; both are in demand for conversion to dwellings. This functional simplicity extends, too, to some of the older whisky distilleries in Scotland, of which the main concentration is in Strath Spey. The malting process is basically the same and the characteristic cowed pyramidal roofs can still be seen here and there.

Town breweries also have an architecture all their own, with pronounced tendencies towards simple and symmetrical Georgian proportions continuing well into the second half of the nineteenth century. External features typically include clocks or clock towers, weather vanes, large lettering proclaiming the name of the firm or the brew and more functional details such as cranes, or 'lucams', above loading bays. Bullard's Anchor Brewery in Norwich (126/TG 231088), dating mainly from the late 1860s, has strongly emphasised arch-headed windows and doors with iron frames, while the somewhat later Tadcaster, Yorkshire, brewery of John Smith's (97/SE 484433), with its ornamental ironwork and spectacular chimney (Plate 102), represents a less common Victorian ornateness. Young's Ram Brewery in Wandsworth (170/TQ 256747) is even more remarkable, with its two working beam engines, of 1835 and 1867, used for driving mashing and milling machinery, as well as coopers' and farriers' shops and stables. Horses are still used regularly for local deliveries.

These are examples of industries that make a visible contribution to the urban or rural landscape and are therefore important not only for the intrinsic characteristics of their own processes but for their role in creating the personality of an area. The industrial archaeologist in studying landscapes is involved in the analysis of their personalities, which depends not only on collecting and collating detailed field evidence and relating it to documentary sources but also on a subtler aesthetic appreciation of the components of that landscape in terms of building materials, of the size and shape of windows, the pitch of roofs, the depths of mouldings and string courses, the design of rainwater goods, the types of paving and road surfacing. Here the work of the industrial archaeologist is wedded immutably with the field evidence, and only by exhaustive and detailed examination of large numbers of structures can he isolate the components that make up the personality of an area. Industrial landscapes, even of the late nineteenth century, possess as much visual variety, structural and architectural indi-



102 John Smith's Tadcaster Brewery, Yorkshire, 1883

viduality as do their rural predecessors, in which the regional variations of the vernacular tradition have long been accepted. The industrial archaeologist in extracting from the surviving buildings and other features of the landscape the specific characteristics that in total create its personality is carrying out a vital archaeological function, and providing what may be the only basis for defining rational conservation policies. He can only analyse those characteristics after recording in painstaking detail large numbers of individual structures and comparing the results. Students of vernacular architecture have long used a system of building record cards which enables a basic tabulation of constructional details, materials, etc. to be made. The technique is as valid for industrial buildings, particularly housing, and the results of analysis contribute in the same way not only to our knowledge of social conditions but also to an understanding of the intangible visual characteristics of an area.

The Industrial Revolution was characterised, we are told, by uniformity and standardisation, by identical machine-made artefacts that could be produced in large numbers. This is to a great extent true, and it poses a peculiar problem of both recording and preservation. It is particularly important to preserve the *typical*, as this represents as closely as possible what

conditions were really like, but it is only by the most diligent processes of archaeological investigation that the characteristics of the typical can be isolated. Having defined a typical row of pitmen's cottages or silk weavers' garrets, the industrial archaeologist is faced with the even greater problem of justifying their retention *because* they are typical, ordinary and everyday. It is only by a detailed knowledge of what those typical characteristics are that a credible case can be made on industrial archaeological grounds.

In South Wales David Anderson and Jeremy Lowe of the Welsh School of Architecture in Cardiff have been able to analyse in detail the characteristics of numerous workers' houses, although unfortunately this has often had to be done in advance of or during the demolition of these houses. They have been able to build up a picture, based largely on the collection of massive quantities of field evidence, of the evolution of house types, providing an insight into the social conditions of the area and the development of techniques of building construction. Now they are able to use their mass of accumulated information as a means of dating, or at least establishing a relative chronology, on the basis of field evidence alone. In their 103 Carpenters' Row, Coalbrookdale, Shropshire. Workers cottages built in the 1790s and now being restored by the Ironbridge Gorge Museum Trust



*Iron Industry Housing Papers* No 2 they examine two cottages, one in Coedpenmaen and the other in Gelligaer, which they describe as 'prototypes', drawing conclusions from a wide variety of constructional features that are compared with other buildings in the area. The absence of beams in the floor construction, the provision of three fireplaces and the use of wall structure above the first floor windows they see in one cottage as being advanced for the late eighteenth century, but the dimensions, particularly of the span, the extensive use of oak and the heavy complex roof suggest an early date, probably before 1811. They recognise both cottages as the continuation of a much earlier seventeenth-century tradition. Physical and documentary evidence combine to pin down the date and their accumulated survey information indicates the coexistence in South Wales in about 1810 of three forms of floor structure—cross-beams alone, cross-beams and joists, and joists alone. They are thus able to make observations based on the collection of comparative evidence, as would the archaeologist of any other period.

The industrial archaeologist, then, can have a valid place in both the processes of data collection and interpretation. The sources available to him are wide, demanding a disciplined and well organised approach but offering in return a vivid insight into the past. This variety of material and documentary evidence and its direct relevance to current society is the key to the involvement of so many people in industrial archaeological investigation, and offers in many ways much wider opportunities for making a fruitful contribution than those afforded to the average amateur digging on a conventional archaeological excavation. The future strength of industrial archaeology rests in this integrated but inter-disciplinary nature of the study, drawing its expertise from a wide range of sources in order to analyse all the available evidence. Few economic historians would today consider writing about industrial sites if they have not examined the physical remains, which is progress in itself, but industrial archaeology offers more than adding an extra dimensional quality to documentary source material. It is the meeting point of people whose motivating interests range from history to complex technologies, from geography or mining geology to architecture or the pure unalloyed aesthetic enjoyment of functional buildings, but whose common inspiration is the physical evidence of the Industrial Revolution, the material heritage of our contemporary culture.

## Appendices:

### 1 Gazetteer of Sites

The majority of the sites listed in this gazetteer are mentioned in the text and a page reference is given with each entry, where appropriate. The gazetteer is arranged under eight regions and within each region the sites are listed in the order of the chapters in this book. There is no standard form of presentation; the information is provided in the form likely to be most convenient to the reader. The geographical descriptions refer to the old (pre-April 1974) county and county borough boundaries. Map numbers refer to the Ordnance Survey 1:50,000 series, an index to which appears on the back cover of all Ordnance Survey sheets. Grid references are presented in the standard form with the grid letters followed by a six-figure reference. In some cases, where an area rather than a specific point is referred to, a four-figure reference is given indicating the kilometre square within which the site comes.

Sites mentioned in the gazetteer which do *not* appear in the text are listed at the end of the appropriate sub-section in italics.

The eight gazetteer regions are

- 1 Scotland
- 2 North West England (Cumberland, Westmorland, Lancashire, The Isle of Man and Cheshire)
- 3 North East England (Northumberland, Durham and Yorkshire)
- 4 The West Midlands (Shropshire, Staffordshire, Herefordshire, Worcestershire, Warwickshire)
- 5 The East Midlands (Derbyshire, Nottinghamshire, Lincolnshire, Leicestershire, Rutland, Northamptonshire)
- 6 The South East (Huntingdonshire, Cambridgeshire, Norfolk, Suffolk, Oxfordshire, Buckinghamshire, Bedfordshire, Hertfordshire, Essex, Berkshire, Greater London, Hampshire, Surrey, Sussex and Kent)
- 7 The South West (Gloucestershire, Somerset, Wiltshire, Cornwall, Devon, Dorset)
- 8 Wales

#### ACCESS TO SITES

Most of the sites described in the text and listed in the gazetteer are on private property, and although the majority can be viewed from public areas, access to them is by

courtesy of the owners. It must be remembered that in many cases owners are unaware of the significance of their buildings or plant. Visitors are advised to make prior arrangement and on no account to regard access as automatically forthcoming. Although some firms welcome individual visitors and even parties, others do not, and often for reasons of safety cannot permit entry to their sites. Remember too that in, for example, derelict mining areas where public access is not restricted there may be hidden shafts or workings. Keep a sharp lookout for these and *never* enter derelict mines without guidance from a local expert who has permission and knows the site well.

## 1 SCOTLAND

## WIND AND WATER POWER

Site	Map	Grid ref	Page
Click Mill, Orkney	6	HY 290200	66
Wanlockhead water pump, Dumfries	68	NS 855144	76
Preston Mill, East Lothian	63	NT 595779	78
<i>Alford watermill, Aberdeen</i>	39	NJ 612167	
<i>Carlisle windmill, Lanark</i>	61	NS 849508	
<i>Hilton windmill, Aberdeen</i>	40	NJ 942342	
<i>Mouswald windmill, Dumfries</i>	74	NY 053736	
<i>Shorrigg windmill, Dumfries</i>	75	NY 162744	

## STEAM AND INTERNAL COMBUSTION POWER

Prestongrange pumping engine, East Lothian	62	NT 374737	103
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## COAL

Prestongrange pumping engine, East Lothian	62	NT 374737	138
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## IRON AND STEEL

Bonawe furnace, Argyllshire	35	NN 114770	154
<i>Carron Ironworks, Stirlingshire</i>	61	NS 880825	
<i>Dalmellington Ironworks, Ayrshire</i>	67	NS 480060	
<i>Muirkirk Ironworks, Ayrshire</i>	67	NS 697268	

## ENGINEERING

<i>Barblues Forge, Airdrie, Lanark</i>	61	NS 803675	
<i>Eagle Foundry, Port Dundas, Glasgow</i>	60	NS 592666	
<i>London Road Foundry, Edinburgh</i>	62	NT 273744	
<i>Macfarlane's Saracen Foundry, Glasgow</i>	60	NS 592683	

Site	Map	Grid ref	Page
<i>New Howe Machine Cycle Works, Glasgow</i>	60	NS 613641	
<i>North British Locomotive Company Works, Glasgow</i>			
<i>Atlas</i>	60	NS 609675	
<i>Hyde Park</i>	60	NS 605675	
<i>Queen's Park</i>	60	NS 593627	
NON-FERROUS METALS			
<i>Wanlockhead water pump, Dumfries</i>	68	NS 855144	210
<i>Copper mines, Bridge of Allan, Stirlingshire</i>	54	NS 795978	
STONE, CLAY AND GLASS			
<i>Glencaise brick kilns, Perthshire</i>	55	NO 193206	220
<i>Alloa glass cones, Clackmannan</i>	55	NS 881924	237
<i>Craigdullycart lineworks, New Cumnock, Ayrshire</i>	67	NS 663153	
TEXTILES			
<i>New Lanark</i>	61	NS 880425	251
<i>Cotton mills, Paisley</i>	60	NS 490635 & 467634	
<i>Woollen mill, Huntly, Aberdeen</i>	30	NJ 532393	
CHEMICALS			
<i>Torbane oil shale site, West Lothian</i>	61	NS 953668	289
<i>Broxbourn oil shale village, West Lothian</i>	61	NT 087728	289
<i>Campsie Alum Works, Lennoxton, Stirling</i>	60	NS 629773	
PUBLIC SERVICES			
<i>Perth Waterworks</i>	55	NO 121232	294
<i>Biggar Gasworks, Lanark</i>	68	NT 038377	300
<i>Maybole Gasworks, Ayrshire</i>	67	NS 303098	
ROADS AND BRIDGES			
<i>Keiso Bridge</i>	70	NT 727336	329
<i>Tongueland Bridge</i>	80	NX 693534	330
<i>Coldstream Bridge</i>	64	NT 848402	330
<i>Dean Bridge, Edinburgh</i>	62	NT 243740	330
<i>Craigellachie Bridge</i>	29	NJ 285452	336
<i>Smeaton's Bridge, Perth</i>	55	NO 121238	
<i>Telford's Carland Craig Bridge, Lanark</i>	61	NS 868445	

Site	Map	Grid ref	Page
RIVERS AND CANALS			
Neptune's staircase locks, Caledonian Canal, Banavie	35	NN 114770	352
<i>Clachnaharry sea lock, Caledonian Canal</i>	28	NH 645468	
<i>Laggan cutting Caledonian Canal</i>	36	NN 286965	
RAILWAYS			
Tramway bridge, Fairlie, Ayrshire	67	NS 383369	371
Tramway bridge, Doura, Ayrshire	59	NS 338423	371
Ballochmyle Viaduct, Ayrshire	67	NS 508254	385
Glenfinnan Viaduct, Inverness	35	NM 910813	385
<i>Connell Railway Bridge, Argyll</i>	46	NM 9134	
<i>Forth Railway Bridge</i>	62	NT 1379	
<i>Tay Railway Bridge</i>	50	NO 395264	
PORTS AND HARBOURS			
Grangemouth Harbour, Stirling	61	NS 925825	401
Portsoy Harbour and Warehouses, Banff	30	NJ 589665	408
<i>Telford breakwater, Aberdeen</i>	40	NJ 962057	
MISCELLANEOUS SITES			
<i>Bucket Mill, Birse, Aberdeen</i>	39	NO 582912	
<i>Edradour distillery, Pitlochry</i>	49	NN 959579	
<i>Horse gin house, Kilwinning Landward, Ayrshire</i>	60	NS 360427	
<i>Ladywell tannery, Maybole, Ayrshire</i>	72	NS 298097	

## 2 NORTH-WEST ENGLAND

## WIND AND WATER POWER

Bidston windmill, Cheshire	100	ST 287894	66
Thornton Cleveleys windmill, Lancs.	94	SD 335426	66
Laxey waterwheel, Isle of Man	87	SC 432852	74
Nether Alderley Mill, Cheshire	101	SJ 844763	78

## STEAM AND INTERNAL COMBUSTION POWER

Dee Mill, Shaw, Rochdale, Lancs	101	SD 945093	112
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## COAL

Astley Green Colliery, Lancs	101	SJ 705990	134
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<i>Site</i>	<i>Map</i>	<i>Grid ref</i>	<i>Page</i>
Worsley Delph, Lancs	101	SD 748005	138
Salford Museum, Buile Hill	101	SJ 799996	140

## IRON AND STEEL

Duddon Furnace, Furness, Lancs	88	SD 197884	154
Newland Furnace, Lancs	88	SD 299798	154
Leighton, Arnside, Lancs	89	SD 485778	154

## ENGINEERING

Walmsley's Atlas Forge, Bolton, Lancs	101	SD 713084	188
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## NON-FERROUS METALS

Goldscope copper mine, Derwentwater	82	NY 228186	
		E 226187	197
Coniston copper mine	88	SD 289986	197
Greenodd copper mine, Lancs	88	SD 315826	197
Tilberthwaite copper mine, Lancs	88	NY 306007	197
Chester shot tower	109	SJ 415667	213

## STONE, CLAY AND GLASS

Pilkington Glass Museum, St Helens, Lancs	100	SJ 498946	238
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## TEXTILES

Hargreaves' cottage, Stanhill, Lancs	95	SD 728277	248
Higher Mill, Helmshore, Lancs	95	SD 777214	248
Frost's Mill, Macclesfield, Cheshire	110	SJ 918737	260
Card factory, Macclesfield, Cheshire	110	SJ 909737	261
Sryal Mill, Cheshire	101	SJ 834830	261
Galgate Mill, Lancs	94	SD 485557	267
Centenary Mill, Preston, Lancs	94	SD 551247	267
Dee Mill, Shaw, Rochdale, Lancs	101	SD 945093	269

## CHEMICALS

Crosceanonby	82	NY 066401	274
Marston salt mine, Northwich, Cheshire	101	SJ 6760	275
Salt sheds, Winsford, Cheshire	110	SJ 599997	275
Winnington, ICI Works, Cheshire	110	SJ 6474	275
Port Sunlight, Cheshire	100	SJ 3484	278

<i>Site</i>	<i>Map</i>	<i>Grid ref</i>	<i>Page</i>
Blackbeck gunpowder mill, Westmorland	89	SD 334859	284
Haverthwaite gunpowder mill, Westmorland	89	NY 328048	284

## PUBLIC SERVICES

Water towers, Ormskirk, Lancs	100	SD 423087 & 423085	295
Water tower, Newton-le-Willows, Lancs	100	SJ 599957	295
Lister Drive power station, Liverpool	100	SJ 387917	307
Tram depot, Chester	109	SJ 413668	312
Horse tram track, Queen Square, Liverpool	100	SJ 346906	312

## ROADS AND BRIDGES

Tollhouse, Todmorden, Lancs	101	SD 945198	323
Central Station, Manchester	101	SJ 837977	326
Grosvenor Bridge, Chester	109	SJ 403656	330
Warrington transporter bridge, Lancs	100	SJ 597877	340
Skerton Bridge, Lancaster	89	SD 479623	330

## RIVERS AND CANALS

Barton Aqueduct, Bridgewater Canal, Lancs	101	SJ 767977	344
Worsley Delph, Lancs	101	SD 748005	344
Worsley Delph, Wharf Crane, Lancs	101	SD 747004	345
Beeston Cast-iron Lock, Cheshire	109	SJ 554599	353
Northgate Locks, Chester	109	SJ 403666	353
Anderton boat lift, Cheshire	101	SJ 647753	354
Preston Brook canal hamlet, Cheshire	109	SJ 568806	356
Barnton Tunnel, Cheshire	110	SJ 630749	356
Saltersford Tunnel, Cheshire	101	SJ 624753	356
Harecastle Tunnel, Staffs	110	SJ 837542	346
Marple Aqueduct, Cheshire	101	SJ 956900	358
Lune Aqueduct, Lancaster	89	SD 484639	358
Ellesmere Port warehouses, Cheshire	109	SJ 405775	364

## RAILWAYS

Viaduct, Earlestown, Lancs	100	SJ 569947	378
Viaduct, Newton-le-Willows, Lancs	100	SJ 591954	378
Skew-arch bridge, Rainhill, Lancs	100	SJ 491914	378
Liverpool Road Station, Manchester	101	SJ 830978	378

<i>Site</i>	<i>Map</i>	<i>Grid ref</i>	<i>Page</i>
Dutton Viaduct, Cheshire	109	SJ 583764	385
Runcorn Viaduct, Cheshire	100	SJ 509835	388
Chester General Station	109	SJ 413669	395
<i>Huskisson memorial, Newton-le-Willows, Lancs</i>	100	SJ 606955	

## PORTS AND SHIPPING

Maryport Harbour, Cumberland	82	NY 030365	401
St George's Quay, Lancaster	94	SD 474623	402
Sunderland Point, nr Lancaster	94	SD 426560	402
Glasson Dock, nr Lancaster	94	SD 445562	403
Barton Swing Aqueduct, Lancs	101	SJ 766976	406
Albert Dock, Liverpool	100	SJ 342897	410
Canning Dock, Liverpool	100	SJ 342899	414
Victoria Tower, Liverpool	100	SJ 333922	414
Floating Landing Stage, Liverpool	100	SJ 337904	414
Sailors' Home, Liverpool (demol)	100	SJ 345900	414
The Albany, Liverpool	100	SJ 340906	415

## MISCELLANEOUS SITES

<i>Arighi Bianchi iron-fronted store, Macclesfield, Cheshire</i>	110	SJ 920737	
<i>Oriel Chambers, Liverpool, curtain wall office</i>	100	SJ 341904	
<i>St George's (cast-iron) Church, Everton, Liverpool</i>	100	SJ 355925	
<i>St Michael's (cast-iron) Church, Aigburth, Liverpool</i>	100	SJ 369871	

## 3 NORTH EAST ENGLAND

## WIND AND WATER POWER

Killhope Lead Mill, Durham	84	NY 827429	74
Lothersdale Watermill, Yorks	95	SD 959459	74
Foster Beck Watermill, Pateley Bridge, Yorks	91	SD 148664	74
Abbeylead industrial hamlet, Sheffield	111	SK 325820	78
Shepherd Wheel, Sheffield	111	SK 117854	78
High Mill, Skipton, Yorks	95	SD 989518	78

## STEAM AND INTERNAL COMBUSTION POWER

Elsecar pumping engine, Yorks	102	SE 390003	84
Ryhope pumping station, Sunderland	78	NZ 403523	102
Beamish winding engine, Durham	78	NZ 220537	110

<i>Site</i>	<i>Map</i>	<i>Grid ref</i>	<i>Page</i>
<b>COAL</b>			
Beamish winding engine, Durham	78	NZ 220537	134
Elemore winding engine, Durham	85	NZ 356456	134
Elsecar pumping engine, Yorks	102	SE 390003	137
Ryhope Colliery, Sunderland	78	NZ 399534	141
Seaham Harbour, Durham	85	NZ 435495	143
Amble Harbour, Northumberland	71	NU 269049	143
Blyth Harbour, Northumberland	78	NZ 3280	143
<b>IRON AND STEEL</b>			
Eston ironstone mines	86	NZ 560186	147
North Skelton ironstone mines	86	NZ 675184	147
Boulby ironstone quarries	86	NZ 760181	147
Rosedale ironstone quarries	92	SE 723946	147
Wortley Forge, Yorks	102	SK 294998	169
Union Bridge, nr Berwick	64	NT 934510	171
Abbeydale industrial hamlet, Yorks	111	SK 326820	174
Hamsterley steel cementation furnace, Durham	78	NZ 131565	172
<b>NON-FERROUS METALS</b>			
Keld Heads lead mill, Yorks	90	SE 077910	209
Cobscar lead mill, Yorks	90	SE 060930	210
Grassington High Mill, Yorks	90	SE 025663	210
Surrender lead mill, Yorks	90	NY 988003	210
Lintzgarth lead mill, Durham	84	NY 925430	210
Castleside lead mill, Durham	84	NZ 078485	210
Langley lead mill, Northumberland	77	NY 841611	211
<b>STONE, CLAY AND GLASS</b>			
Ryedale Folk Museum, Hutton-le-Hole, Yorks	86	SE 705900	234
Catcliffe glass cone, Yorks	103	SE 425887	236
Lemington glass cone, Newcastle-upon-Tyne	78	NZ 184646	237
<b>TEXTILES</b>			
Gott's Mill, Leeds (demol)	96	SE 291335	269
Marshall's Mill, Leeds	96	SE 295326	270
Manningham Mills, Bradford	96	SE 146348	272

Site	Map	Grid ref	Page
Otterburn woollen mill, Northumberland	77	NY 888926	
Saltaire, Bradford	96	SE 140381	

## CHEMICALS

Seaton Sluice, Northumberland	78	NZ 336768	275
Ravenscar alum shale quarries, Yorks	93	NZ 9701	281
Boulby alum shale quarries, Yorks	86	NZ 7519	281
Kettlewell alum shale quarries, Yorks	86	NZ 8415	281
Sandsend alum wharf, Yorks	86	NZ 862128	281

## PUBLIC SERVICES

Ryhope water pumping station, Sunderland	78	NZ 404525	294
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## ROADS AND BRIDGES

Union Bridge, nr Berwick	64	NT 934511	337
Royal Tweed Bridge, Berwick	64	NT 995528	339
Middlesbrough transporter bridge	85	NZ 500213	340

## RIVERS AND CANALS

Bingley five-rise locks, Yorks	96	SE 108400	352
Standedge Tunnel, Yorks	102	SE 006079	
		to 040120	356

## RAILWAYS

Jarrow staithes, Durham	78	NZ 353650	368
Causey Arch, Durham	78	NZ 220537	368
Tramway earthworks, High Spenn, Durham	78	NZ 137596	368
Weigh-house, Brampton Sands, Cumberland	76	NY 550600	369
Tramway earthworks, Kirkhouse, Cumberland	76	NY 567599	369
Tramway earthworks, Monkwearas Brow, Cumberland	82	NX 969167	369
Stockton & Darlington sleeper blocks, Brusselton, Durham	85	NZ 195255	377
Stockton & Darlington earthworks, Low Etherley	85	NZ 170289	377
Railway Bridge, Darlington North Road	85	NZ 289157	377
Darlington Bank Top Station	85	NZ 294140	377
Grosmont Tunnel, Yorks	86	NZ 829051	392
Bramhope Tunnel, Yorks	96	SE 256438	
		to 242408	392

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Otley churchyard memorial	96	SE 202455	392
Huddersfield Station, Yorks	102	SE 144169	395
Monkwearmouth Station, Sunderland	78	NZ 396577	395
Newcastle Central Station	78	NZ 245638	395
Haworth station (K&WVR), Yorks	96	SE 035373	398
High Level Bridge, Newcastle-upon-Tyne	78	NZ 252633	

## PORTS AND SHIPPING

Seaham Harbour, Durham	85	NZ 435495	401
Goole Harbour, Yorks	98	SE 745230	401
Newcastle-upon-Tyne swing bridge	78	NZ 253637	406

## MISCELLANEOUS SITES

Tadcaster Brewery, Yorks	97	SE 484433	424
Horse-gin, Great Ayton, Yorks	86	NZ 370075	
Horse Gin House, Wall, Northumberland	77	NY 931695	

## 4 THE WEST MIDLANDS

## WIND AND WATER POWER

Forge Needle Mill, Redditch	131	SP 046686	78
Cheddleton Flint Mill, Staffs	110	SJ 973526	78
Chesterton windmill, Warks	132	SP 347594	

## COAL

Blists Hill Open Air Museum, nr Ironbridge, Shropshire	119	SJ 694031	130
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## IRON AND STEEL

Charlcombe Furnace, Shropshire	129	SO 638861	154
Darby Furnace, Coalbrookdale, Shropshire	119	SJ 667047	157
Bedlam Furnaces, Ironbridge, Shropshire	119	SJ 677034	157
Blists Hill Open Air Museum, nr Ironbridge, Shropshire	119	SJ 693033	159
Bloomer's Chain Works, Cradley Heath, Worcs	131	SJ 929862	170
Avoncroft Museum of Buildings, Worcs	131	SO 950684	170

## NON-FERROUS METALS

Snailbeach lead mines, Shropshire	118	SJ 375022	207
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<i>Site</i>	<i>Map</i>	<i>Grid ref</i>	<i>Page</i>
STONE, CLAY AND GLASS			
Black Country Museum, Dudley	131	SO 949917	221
Free Bridge, Ironbridge, Shropshire	119	SJ 681033	224
Cheddleton Flint Mill, Staffs	110	SJ 974525	228
Gladstone Pottery, Longton, Staffs	110	SJ 912434	231
Coalport Pottery, Shropshire	119	SJ 695024	231
Stourbridge glass cone, Worcs	130	SO 894864	237
TEXTILES			
Bage's Mill, Shrewsbury	118	SJ 500140	264
CHEMICALS			
Tar Tunnel, Coalport, Shropshire	119	SJ 694025	289
PUBLIC SERVICES			
Coleham sewage pumping station, Shrewsbury	118	SJ 496121	296
ROADS AND BRIDGES			
Staffordshire County Museum, Shugborough	119	SJ 991224	324
Milepost, Craven Arms, Shropshire	129	SO 433827	325
Montford Bridge, Shropshire	118	SJ 433153	330
Iron Bridge, Shropshire	118	SJ 673034	330
Buildwas Bridge, Shropshire	118	SJ 645044	334
Coalport Bridge, Shropshire	119	SJ 702021	334
Cound Bridge, Shropshire	118	SJ 556053	334
Holt Fleet Bridge, Ombersley, Worcs	130	SO 824634	336
Galton Bridge, Smethwick	131	SP 015894	336
RIVERS AND CANALS			
Brindley Mill, Leek, Staffs	110	SJ 977570	343
Harecastle Tunnel, Staffs	110	SJ 837542	346
		to 849517	346
Tyrley cutting, Shropshire	119	SJ 693315	346
Guillotine locks, Hadley, Shropshire	119	SJ 672133	
		& 674131	350
Tardebigge Locks, Worcs	131	SO 985685	350
Bratch Locks, Worcs	130	SO 867938	352
Botterham Locks, Worcs	130	SO 860914	352

<i>Site</i>	<i>Map</i>	<i>Grid ref</i>	<i>Page</i>
Compton Lock, Worcs	130	SO 884989	353
Coalport inclined plane, Shropshire	119	SJ 695028	354
Dove Aqueduct, Burton-on-Trent, Staffs	120	SK 269269	358
Great Haywood Aqueduct, Staffs	119	SJ 994229	358
Milford Aqueduct	119	SJ 973215	358
Longden-upon-Tern Aqueduct, Shropshire	118	SJ 617156	359
Chirk Aqueduct, Shropshire	118	SJ 287372	360
Stourport, inland port, Worcs	130	SO 810710	363
<i>Stretton Aqueduct, Staffs</i>	<i>119</i>	<i>SJ 873107</i>	

## RAILWAYS

Froghall basin terminus, Caldon Canal, Staffs	111	SK 028477	369
Remains of tramway bridge, Woodcock, Staffs	111	SK 070480	369
Tramway bridge, Whiston, Staffs	111	SK 029476	369
Curzon Street Station, Birmingham	131	SP 080871	380
Albert Edward Bridge, Ironbridge, Shropshire	118	SJ 661038	391
Shugborough Tunnel, Staffs	119	SJ 982216	392
		to 988216	395
Stoke-on-Trent Station, Staffs	110	SJ 879456	396
Shrewsbury Station	118	SJ 494129	396
Stone Station, Staffs	119	SJ 896346	399
Bridgnorth Station, Shropshire	130	SO 715926	000

## 5 THE EAST MIDLANDS

## WIND AND WATER POWER

Maud Foster windmill, Boston, Lincs	114	TF 333447	61
Burgh-le-Marsh windmill, Lincs	114	TF 504650	61
Alford windmill, Lincs	114	TF 457766	61
Sibsey windmill, Lincs	114	TF 344510	61
Heckington windmill, Lincs	113	TF 145436	61

## STEAM AND INTERNAL COMBUSTION POWER

Papplewick pumping station, Notts	112	SK 583522	101
Abbey Lane pumping station, Leicester	121	SK 589066	101

## COAL

Snibston Colliery, Leics	121	SK 417145	130
Lound Hall Mining Museum, Notts	112	SK 701731	130

Site	Map	Grid ref	Page
Wollaton Hall Industrial Museum, Nottingham	112	SK 531393	132
Thringstone Colliery, Leics	121	SK 424183	138

## IRON AND STEEL

<i>Morley Park blast furnaces, Heage, Derbys</i>	111	SK 380492	
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## NON-FERROUS METALS

Maggie Mine, Sheldon, Derbys	111	SK 173682	207
Stone Edge lead mill, Derbys	111	SK 334670	211
Alport leadmill, Derbys	111	SK 223648	211

## STONE, CLAY AND GLASS

Measham bricks, Leics	120	SK 334122	218
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## TEXTILES

Cotchett's silk mill, Derby	121	SK 345365	256
Old Mill, Cromford, Derbys	111	SK 298569	260
Masson Mills, Cromford, Derbys	111	SK 294573	260
Cressbrook Mill, Derbys	111	SK 173728	260
Calver Mill, Derbys	111	SK 245744	262
North Mill, Belper, Derbys	111	SK 346480	264
Viyella factory, Nottingham	112	SK 570394	267

## CHEMICALS

Eakring oil field, Notts	112	SK 6762	289
Plungar oil field, Leics	112	SK 7734	289

## PUBLIC SERVICES

Papplewick water pumping station, Notts	112	SK 582522	294
Abbey Lane sewage pumping station, Leicester	121	SK 589066	297
Crich Tramway Museum, Derbys	111	SK 345348	311
Tram terminus, Ashby-de-la-Zouch, Leics	121	SK 353164	312

## ROADS AND BRIDGES

Swarkeston Bridge, Derbys	121	SK 369285	317
Shardlow tollhouse board, Derbys	121	SK 442303	324

## RIVERS AND CANALS

Fossdyke, Notts and Lincs	104	SK 837781	341
	to 113	SK 970713	341

<i>Site</i>	<i>Map</i>	<i>Grid ref</i>	<i>Page</i>
Waterways Museum, Stoke Bruerne, Northants	146	SP 743500	357
Foxton Locks, Leics	133	SP 692895	351
Blisworth Tunnel, Northants	146	SP 729529	
		to 739503	357
Shardlow, inland port, Derbys	121	SK 444304	363

## RAILWAYS

Buxworth basin, Derbys	111	SK 020820	369
Tramway tunnel, Chapel Milton, Derbys	111	SK 058817	369
Tramway bridge, Ticknall, Derbys	121	SK 356240	370
Tramway tunnel, Ticknall, Derbys	121	SK 355238	370
Blisworth Tunnel, Northants	146	SP 729529	
		to 739503	370
Middleton Top winding engine, Derbys	111	SK 275552	370
Tramway bridge, Stratford-upon-Avon	144	SP 205548	371
Bagworth crossing house, Leics	121	SK 446091	379
Road cutting, Northants	146	SP 750525	379
Kilsby Tunnel, Northants	133	SP 565715	
		to 578697	379
Harringworth Viaduct, Rutland	133	SP 914975	385
Friargate Bridge, Derby	121	SK 347364	391
Glenfield Tunnel, Leics	121	SK 545065	
		to 561061	392
Woodhead Tunnel, Derbys	102	SK 114999	392
Redhill Tunnel, Notts	121	SK 496308	392
Ashby-de-la-Zouch Station, Leics	121	SK 355163	395

## PORTS AND SHIPPING

Grimby hydraulic tower, Lincs	105	TA 281113	405
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## MISCELLANEOUS SITES

Manfield Building, Campbell Square, Northampton	133	SP 755609	422
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## 6 THE SOUTH EAST

## WIND AND WATER POWER

Chillenden windmill, Kent	173	TR 268543	56
Bourn windmill, Cambs	134	TL 312580	56

Holton windmill, Suffolk	137	TM	402776	56
Pitstone windmill, Bucks	159	SP	945157	56
Wheatley windmill, Oxon	158	SP	589052	57
West Wittering windmill, Sussex	181	SZ	797972	57
Willingham windmill, Cambs	135	TL	404697	57
Cranbrook windmill, Kent	172	TQ	779359	57
St Margaret's Bay windmill, Kent	173	TR	363435	57
Bembridge windmill, Isle of Wight	180	SZ	640875	58
Herne windmill, Kent	173	TR	184665	59
Great Bardfield windmill, Essex	148	TL	681308	59
Polegate windmill, Sussex	183	TQ	581041	59
Selsey windmill, Sussex	181	SZ	843933	59
West Wrating windmill, Cambs	148	TL	604510	59
Burwell windmill, Cambs	135	TL	590665	60
Outwood windmill, Surrey	170	TQ	327456	60
Saxted Green windmill, Suffolk	137	TM	254644	63
Great Chishill windmill, Cambs	148	TL	413388	63
Cross-in-Hand windmill, Sussex	183	TQ	558218	63
Wicken Fen windmill, Cambs	135	TL	562706	65
Horsey windmill, Norfolk	126	TG	457223	65
Berney Arms windmill, Norfolk	126	TG	465051	65
Woodbridge tide mill, Suffolk	150	TM	276847	74
<i>Deben Watermill, Wickham Market, Suffolk</i>	150	TM	306566	
<i>Drinkstone windmill, Suffolk</i>	136	TL	964622	
<i>Morden snuff mills, Merton</i>	170	TQ	262686	

## STEAM AND INTERNAL COMBUSTION POWER

Ram Brewery, Wandsworth, London	170	TQ	256747	92
Stretham pump, Cambs	135	TL	517730	93
Eastney pumping station, Portsmouth	181	SZ	675989	102
Kempton Park pumping station, Hounslow, London	170	TQ	110709	112
Otterbourn pumping station, Hants (demol)	168	SU	468233	112

## IRON AND STEEL

Weald and Downland Open Air Museum, Sussex	181	SU	875130	151
Hawkins Pond, Sussex	182	TQ	217292	151
Hammer Pond, Sussex	182	TQ	219289	151
Slaugham Pond, Sussex	182	TQ	248281	151

Cort's furnace site, Funtley, Hants	180	SU	550082	165
Sheerness boatsheds, Kent	172	TQ	910753	172

## STONE, CLAY AND GLASS

Betchworth limekilns, Surrey	170	TQ	208514	222
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## TEXTILES

Fournier Street silk weavers' houses, London	160	TQ	338818	258
Silk mill, Whitechurch, Hants	168	SU	464481	261
<i>Yarn Mill, Cowgate, Norwich (now Jarrold's)</i>	126	TG	235092	

## CHEMICALS

Faversham gunpowder mills, Kent	172	TR	009613	284
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## PUBLIC SERVICES

Water supply ponds, Islington, London	160	TQ	313828	292
New River conduit, London	160	TQ	318878	292
	160	TQ	343987	293
	160	TQ	306916	293
Kew Bridge water pumping station, Brentford, London	170	TQ	188780	294
Water tower, Godalming, Surrey	170	SU	970445	295
Sewage pumping station, Greenwich	161	TQ	377772	296
Abbey mills sewage pumping station, West Ham	161	TQ	388832	296
Crossness sewage pumping station, Thamesmead	161	TQ	484811	296
Eastney sewage pumping station, Portsmouth	181	SZ	675989	297
Webb sewer lamp, Carting Lane, London	160	TQ	305806	298
Fakenham Gasworks, Norfolk	125	TF	919293	300
Fulham Gasworks, London	170	TQ	260768	301
Reading Gasworks, Berkshire	169	SU	731738	301
Deptford power station, London	161	TQ	374779	305
Volk's Electric Railway, Brighton, Sussex	182	TQ	316038	310
Kingsway tram subway, London	160	TQ	305817	312
Semaphore station, Chatley Heath, Surrey	170	TQ	089585	314

## ROADS AND BRIDGES

Wagon-weighing machine, Woodbridge, Suffolk	150	TM	272491	325
Tickford Bridge, Newport Pagnell, Bucks	146	SP	877437	334
Marlow suspension bridge, Bucks	159	SU	852862	338

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RIVERS AND CANALS			
Eynsham flash lock, Oxon	158	SP 446089	343
Castle Mills staunch, Beds	147	TL 094509	343
Tuddenham Mill stream, staunch	135	TL 732729	343
Bottisham Lode, staunch	135	TL 516651	343
Papercourt turf locks, R. Wey, Surrey	170	TQ 034568	347
Walsham gates	170	TQ 050578	347
Worsfold gates, nr Send, Surrey	170	TQ 016557	350
Sheffield turf lock, Berkshire	158	SU 649706	347
RAILWAYS			
Surrey Iron Railway track, Purley	170	TQ 316622	371
		TQ 290543	371
Surrey Iron Railway track, Wallington	170	TQ 288638	371
Tring cutting, Herts	159	SP 940137	379
Camden roundhouse, London	160	TQ 282843	380
Hanwell Viaduct, Middlesex	160	TQ 150804	381
Maidenhead Viaduct, Berks	159	SU 901810	381
Sonning cutting, Berks	159	SU 759743	381
Primrose Hill Tunnel, London (South portal)	160	TQ 276843	392
Kings Cross Station, London	160	TQ 303831	394
St Pancras Station, London	160	TQ 302829	394
Cambridge Station	135	TL 462573	395
Maldon Station, Essex	162	TL 853077	396
Southampton (L&SR) Station	180	SU 422109	396
Sheffield Park Station, Sussex	183	TQ 404237	398
<i>Battle Station, Sussex</i>	184	TQ 755156	
PORTS AND SHIPPING			
Tower Bridge, London	160	TQ 337802	406
St Katharine's Dock, London	160	TQ 339805	409
Dockside crane, Harwich	150	TM 262325	415
Chatham boat store	172	TQ 765700	419
Sheerness boatshed	172	TQ 910753	419
Portsmouth dockyard storehouse	180	SU 630005	419
<i>Cutty Sark, Greenwich</i>	171	TQ 383781	
<i>HMS Victory, Portsmouth</i>	180	SU 630001	

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MISCELLANEOUS SITES			
Bullard's Brewery, Norwich	126	TG 231088	424
Snape maltings, Suffolk	137	TM 392575	423
<i>Abbot's Hall Museum, Stowmarket, Suffolk</i>	136	TM 047585	
<i>Donkey wheel, Beech, nr Alton, Hants</i>	169	SU 688386	
<i>Maltings, Ipswich Dock, Suffolk</i>	150	TM 167437	
<i>Mistley Maltings, Essex</i>	150	TM 324319	

## 7 THE SOUTH WEST

## WIND AND WATER POWER

Chapel Allerton windmill, Somerset	165	ST 414504	56
High Ham windmill, Somerset	165	ST 433305	57
Wilton windmill, Wiltshire	167	SU 276617	59
Wheal Martyn waterwheel, Cornwall	185	SX 004555	76
Claverton water pump, Somerset	166	ST 791644	77
Priston Watermill, Somerset	166	ST 695615	77
Sticklepath scythe works, Devon	175	SX 643940	78
Tolgus tin streaming works, Cornwall	189	SW 690438	78

## STEAM AND INTERNAL COMBUSTION POWER

Hawkesbury beam engine, Dartmouth, Devon	188	SX 879515	83
East Pool engines, Camborne, Cornwall	189	SW 674416	
		& 675419	103
Levant mine engine, Cornwall	189	SW 375346	103
Crofton pumping station, Wilt	167	SU 262623	103
Underfall Yard workshops, Bristol	156	ST 572722	110

## COAL

New Rock Colliery, Somerset	166	ST 647505	130
Nailsea Colliery engine house, Somerset	165	ST 479691	138

## IRON AND STEEL

Sticklepath scythe works, Devon	175	SX 639940	169
<i>Coleford blast furnace, Glos</i>	142	SO 577720	

## ENGINEERING

Underfall Yard workshops, Bristol	156	ST 572722	188
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NON-FERROUS METALS			
South Crofty tin mine, Cornwall	189	SW 669409	194
Geevor tin mine, Cornwall	189	SW 375345	194
Copperhouse, Hayle, Cornwall	189	SW 568380	198
Calamine oven, Shipham, Somerset	165	ST 445574	199
Keynsham brass mills, Somerset	156	ST 657688	200
Saltford brass mills, Somerset	156	ST 687671	200
Kelston brass mills, Somerset	156	ST 695680	200
Warmley brass works, nr Bristol	156	ST 668728	200
Levant copper mine, Cornwall	189	SW 360340	204
Robinson's Shaft, South Crofty, Cornwall	189	SW 669409	205
East Pool engines, Camborne, Cornwall	189	SW 674416	
		& 679419	205
Holman's Museum, Camborne, Cornwall	189	SW 647401	205
Nancledra stamps, Cornwall	189	SW 500355	205
Tolgus tin streaming works, Cornwall	189	SW 690438	205
Priddy lead workings, Somerset	165	ST 545508	209
Charterhouse lead workings, Somerset	165	ST 504557	210
Smitham Hill lead smelter, Somerset	165	ST 556547	211
Crews Hole chimney, Bristol	156	ST 625733	211
Devon Great Consols Mine, Devon	175	SX 425733	212
Botallack Mine, Cornwall	189	SW 363333	212
STONE, CLAY AND GLASS			
Concrete-frame tobacco warehouse, Bristol	156	ST 567723	224
Seaton concrete bridge, Devon	177	SY 253900	224
Wheal Marryn clayworks, Cornwall	185	SX 004555	226
Parkandillack clayworks, Cornwall	185	SW 945568	227
Goonvean clayworks, Cornwall	185	SW 947552	227
Carthew clayworks, Cornwall	185	SW 997554	227
Wendron Forge, Cornwall	189	SW 680315	228
Bristol glass cone	156	ST 592723	238
Harvey's Wine Museum, Bristol	156	ST 584729	239
Portland stone quarries, Dorset	178	SY 6972	
TEXTILES			
Stanley Mill, Stroud, Glos	156	SO 813043	265
Avon Mill, Malmesbury, Glos	157	ST 936869	
Dunkirk Mill, Nailsworth, Glos	156	SO 844005	

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<b>CHEMICALS</b>			
Salt evaporation pools, Lymington, Hants	180	SZ 315923	274
Soap factory, Broad Plain, Bristol	156	ST 597728	276
Logwood Mill, Keynsham, Somerset	156	ST 656679	279
Powder Mills Farm, nr Princetown, Devon	175	ST 628769	284
Powder House, Bristol	156	ST 537765	285
Bathford paper mill, Somerset	156	ST 790671	287
Wookey Hole paper mill, Somerset	165	ST 531466	287
Slaughterford rag mill, Glos	156	ST 839738	287
Oil shale extraction plant, Kilve, Somerset	164	ST 147439	289
<b>PUBLIC SERVICES</b>			
Blagdon water pumping station, Somerset	165	ST 503600	294
Chelvey water pumping station, Somerset	165	ST 474679	294
Bristol electricity power stations	156	ST 594728 & 593728	305
<b>ROADS AND BRIDGES</b>			
Ashton Gate tollhouse, Bristol	156	ST 573717	324
Cast-iron finger post, Bristol	156	ST 599718	325
Over Bridge, Gloucester	143	SO 817196	330
Iron bridges over Kennet & Avon Canal, Bath	156	ST 758654	334
Iron bridge, Tewkesbury, Glos	143	SO 893330	334
Mythe Bridge, Tewkesbury, Glos	143	SO 888337	336
Victoria Bridge, Bath	156	ST 741650	338
Clifton suspension bridge, Bristol	156	ST 564731	338
Royal Albert Bridge, Saltash, Cornwall	187	SX 435587	338
Seaton, concrete bridge, Devon	177	SY 253900	339
<b>RIVERS AND CANALS</b>			
Combe Hay locks, Somerset	166	ST 748604	351
Ridd incline, Devon	163	SS 476217	354
Sapperton Tunnel, Glos	157	SO 966006 to 944034	357
Dundas Aqueduct, Monkton Combe, Somerset	166	ST 784625	358
Avoncliff Aqueduct, Somerset	166	ST 805600	358
Devizes Locks, Kennet & Avon Canal, Wilts	167	ST 980615	

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<b>RAILWAYS</b>			
Combe Hay tramway incline, Somerset	166	ST 748604	370
Morwellham quay and tramway, Devon	187	SX 446698	370
Box Tunnel, Wilts (west portal)	156	ST 829689	381
Chepstow Bridge, Glos	136	ST 539941	387
Meldon Viaduct, Devon	175	SX 565924	389
New Passage pier and hotel, Glos	155	ST 544864	393
Bath, Green Park Station	166	SO 745647	396
Bristol, Temple Meads Station	156	ST 596724	396
Starcross pumping station, Devon	176	SX 977819	396
Buckfastleigh Station, Devon	188	SX 746663	399
<i>Brunel viaduct piers, Liskeard</i>	186	SX 236640	
<i>Haytor Granite Railway, Devon</i>	188	SX 762778	
<b>PORTS AND SHIPPING</b>			
Sea Mills Harbour, Bristol	155	ST 550760	400
Cumberland basin, Bristol	156	ST 570723	403
Underfall Yard workshops, Bristol	156	ST 572722	405
Prince's Street Bridge, Bristol	156	ST 586723	405
Bush's warehouse, Bristol	156	ST 586725	408
Bathurst basin warehouses, Bristol	156	ST 587722	408
Welsh Back warehouses, Bristol	156	ST 588726	408
Heavy lift crane, Bristol	156	ST 584722	417
Smeaton's Eddystone lighthouse, Plymouth	187	SX 478538	417
Great Western Dock, Bristol, and ss <i>Great Britain</i>	156	ST 578724	418
<b>8 WALES</b>			
<b>WIND AND WATER POWER</b>			
<i>Carew tide mill, Pembs</i>	131	SN 046038	
<i>Dinorwic quarries waterwheel, Caernarvon</i>	107	SH 586602	
<i>Llandegai Watermill, Caernarvon</i>	107	SH 602698	
<i>Pont-y-Felin Watermill, Caernarvon</i>	115	SH 480435	
<b>COAL</b>			
Old Glyn Pit, Pontypool	154	ST 265999	134
Trehafod Colliery	154	ST 036910	140
Abergorki Colliery	154	ST 050990	141

<i>Site</i>	<i>Map</i>	<i>Grid ref</i>	<i>Page</i>
<b>IRON AND STEEL</b>			
<i>Blaenavon iron furnaces, Monmouth</i>	154	SO 250090	
<b>NON-FERROUS METALS</b>			
<i>Parys Mountain, Anglesey</i>	106	SH 4490	198
<i>Amlwch, Anglesey</i>	106	SH 449934	199
<i>Parys Mountain windmill, Anglesey</i>	106	SH 444906	199
<i>Cydweli tinplate works</i>	152	SN 421079	202
<i>Melngriffith pump, nr Cardiff</i>	154	ST 142801	203
<i>Dolaucothi gold mines, Carmar</i>	140	SN 670410	213
<i>Gwynfynydd gold mines, Merioneth</i>	116	SH 735275 & 737282	213
<b>STONE, CLAY AND GLASS</b>			
<i>Penthyon slate quarries, Caernarvon</i>	107	SH 6265	216
<i>Blaenau Ffestiniog slate quarries</i>	107	SH 7046	216
<i>Llanberis slate quarries</i>	107	SH 5960	216
<b>TEXTILES</b>			
<i>Welsh Folk Museum, St Fagans, Cardiff</i>	154	ST 118772	252
<b>PUBLIC SERVICES</b>			
<i>Lake Vyrnwy reservoir, Montgomery</i>	117	SJ 018193	293
<i>Dolgellau Gasworks, Merioneth</i>	116	SH 729179	301
<i>Great Orme Railway, Llandudno</i>	107	SH 777827	312
<b>ROADS AND BRIDGES</b>			
<i>Sychnant Pass, Caernarvon</i>	107	SH 750770	321
<i>Llanfair PG tollhouse, Anglesey</i>	107	SH 532715	323
<i>Pontypridd Bridge</i>	154	ST 074904	330
<i>Waterloo Bridge, Bettws-y-Coed</i>	107	SH 799558	334
<i>Menai suspension bridge</i>	107	SH 556714	337
<i>Conway suspension bridge</i>	107	SH 786777	338
<i>Newport transporter bridge, Mon</i>	155	ST 318863	340
<b>RIVERS AND CANALS</b>			
<i>Pont Cysyllte Aqueduct, Denbighshire</i>	117	SJ 271420	361
<i>Llanfoist wharf, Brecon Canal</i>	142	SO 285130	

<i>Site</i>	<i>Map</i>	<i>Grid ref</i>	<i>Page</i>
RAILWAYS			
Pwll-Ddu tramway tunnel, Mon	141	SO 248114	370
Tramway bridge, Redbrook, Mon	142	SO 537103	370
Penydarran Tramway remains	154	ST 083969	372
Britannia Bridge, Caernarvonshire	107	SH 542710	385
Conway Bridge, Caernarvonshire	107	SH 787776	386
Barmouth timber viaduct, Merioneth	116	SH 624150	391
Penrhyndeudraeth timber viaduct, Merioneth	116	SH 619384	391
Ffestiniog Tunnel, Merioneth	107	SH 687505	391
		to 697469	
Blackrock Pier, Mon	155	ST 514881	393
Sudbrook pumping station, Mon	155	ST 507874	393
Tywyn Station, Merioneth	127	SH 586005	398
Abergynolwyn Station, Merioneth	127	SH 671064	398
Porthmadog Station (FR), Caernarvon	116	SH 571384	398
Llanfair Caereinion Station, Montgomery	117	SJ 106068	398
Aberystwyth Station (V of RR), Cardigan	127	SN 585815	398
Devil's Bridge Station, Cardigan	127	SN 738769	398
Llanberis station, Snowdon Railway, Caernarvon	107	SH 583597	398
<i>Tramway Bridge, Aberdare</i>	154	SN 997037	

## 2 Museums of Industry

### MUSEUMS OF INDUSTRY

The following are the principal museums holding industrial, technological and transport material. They are listed alphabetically by place and the entries in column two refer to the type of industrial material in the collection—thus 'textiles' means textile machinery and so on.

- |   |   |
|---|---|
| ANSTRUTHER (Fife)<br>Scottish Fisheries Museum,<br>St Ayles, Harbourhead, Anstruther<br>Tel: Anstruther 628   | Scottish fisheries                                  |
| BANGOR (Caernarvon)<br>Penrhyn Castle Locomotive and<br>Industrial Museum,<br>Penrhyn Castle, Bangor  | Railways, slate transport                           |
| BEAMISH (County Durham)<br>North of England Open Air Museum,<br>Beamish Hall, Stanley, County Durham<br>Tel: Stanley (02073) 3586   | Industry and social history of the<br>North East    |
| BEAULIEU (Hampshire)<br>Buckler's Hard Maritime Museum,<br>Buckler's Hard, Beaulieu, Brockenhurst<br>Tel: Buckler's Hard 203<br>National Motor Museum,<br>Palace House, Beaulieu<br>Tel: Beaulieu 374 | Maritime<br><br>Motor vehicles                      |
| BIRMINGHAM<br>Avery Historical Museum,<br>W. & T. Avery Ltd,<br>Soho Foundry, Birmingham 40<br>Tel: (021) 558 1112  | Company museum, weighing<br>(appointment preferred) |

- Museum of Science & Industry, Science, engineering, transport  
 Newhall Street, Birmingham B3 1RZ  
 Tel: (021) 236 1022
- Sarehole Mill, Cole Bank Road, Watermill  
 Hall Green, Birmingham  
 (administered by City Museum & Art Gallery)  
 Tel: (021) 777 6612
- BLACKBURN (Lancashire) Textiles  
 Lewis Museum of Textile Machinery,  
 Exchange Street, Blackburn  
 Tel: (0254) 59511
- BRADFORD (Yorkshire) Textiles, engineering, transport  
 Industrial Museum, Moorside Mills,  
 Moorside Road, Eccleshill, Bradford
- BRISTOL  
 Blaise Castle House Museum, Local crafts, watermill (Stratford Mill)  
 Henbury, Bristol BS10 7QS  
 Tel: (0272) 625378
- City Museum, Industry (mainly in store), maritime,  
 Queen's Road, Bristol BS8 1RL transport  
 Tel: (0272) 299771
- Harvey's Wine Museum Company Museum, wine, bottles  
 12 Denmark Street, Bristol  
 Tel: (0272) 20164
- CAMBORNE (Cornwall)  
 Holman Museum, (Holman Brothers Ltd) Mining engineering, local industry  
 Camborne  
 School of Mines Museum, Camborne Mining engineering
- CARDIFF  
 National Museum of Wales, Welsh industry, mining, steel, tinplate,  
 Cathays Park, Cardiff CF1 3NP quarrying, shipping  
 Tel: (0222) 26241
- Welsh Folk Museum, St Fagans, Welsh craft industries,  
 Cardiff CF5 6XB woollen mill, tannery  
 Tel: (0222) 561357

- CASTLETOWN** (Isle of Man) Maritime. Schooner-rigged yacht  
Nautical Museum, Bridge Street, *Peggy, 1789*  
Castletown (administered by the  
Manx Museum)
- COALBROOKDALE** (see Telford)
- COVENTRY** Road transport, textiles, aeronautics  
Herbert Art Gallery & Museum,  
Jordan Well, Coventry CV1 5QP  
Tel: (0203) 25555
- CRICH** (Derbyshire) Trams  
Tramway Museum, Matlock Road,  
Crich, near Matlock, Derbyshire DE4 5DP  
Tel: (077 385) 2565  
(Grid ref: 111 SK 345548)
- DERBY** Local industry, textiles, aeronautics  
Museum of Industry & Technology,  
Silk Mill Lane, Derby
- ECCLES** (Lancashire) Nasmyth machinery  
Monks Hall Museum,  
42 Wellington Road, Eccles,  
Lancashire M30 0NP  
Tel: (061) 789 4372
- EDINBURGH** Science, engineering, transport,  
aeronautics, mining  
Royal Scottish Museum,  
Chambers Street, Edinburgh EH1 1JF  
Tel: (031) 225 7534
- EXETER** (Devon) Maritime, mainly sailing craft  
Exeter Maritime Museum, The Quay,  
Exeter EX2 4AN  
Tel: (0392) 58075

## GLASGOW

Art Gallery & Museum, Maritime engineering  
 Kelvingrove, Glasgow C3

Tel: (041) 334 1134

Museum of Transport, 25 Albert Drive, Transport  
 Glasgow S1

Tel: (041) 423 8000

## HALIFAX (Yorkshire)

Bankfield Museum & Art Gallery, Textiles  
 Akroyd Park, Halifax

Tel: (0422) 54823

West Yorkshire Folk Museum, Local industry, transport  
 Shibden Hall, Shibden, Halifax

Tel: (0422) 52246

## HARTLEBURY (Worcestershire)

Worcestershire County Museum, Local industry, carpets, transport  
 Hartlebury Castle, nr Kidderminster

Tel: Hartlebury 416

## HARTLEPOOL (County Durham)

Maritime Museum, Northgate, Maritime, fishery  
 Hartlepool

## HULL (Yorkshire)

Maritime Museum, Pickering Road, Maritime  
 Hessle Road, Kingston upon Hull

Tel: (0482) 51936

Transport & Archaeology Museum, Transport  
 36 High Street, Kingston upon Hull

Tel: (0482) 27625

## IRONBRIDGE (see Telford)

## LEICESTER

Museum of Technology, Abbey Lane Industry of the East Midlands, transport  
 Pumping Station,  
 Corporation Road, Leicester

Tel: (0533) 61330

Railway Museum, London Road, Railways  
 Stoneygate, Leicester

- LIVERPOOL** Land transport, maritime  
 Merseyside County Museums,  
 William Brown Street, Liverpool L3 8EN  
 Tel: (051) 207 0001
- LLANBERIS** (Caernarvon) Slate quarrying, iron founding,  
 North Wales Quarrying Museum, engineering  
 Llanberis  
 Tel: Llanberis 630
- LONDON** Maritime  
 National Maritime Museum,  
 Romney Road, Greenwich,  
 London SE10 9NF  
 Tel: (01) 858 4422  
 Science Museum, Science, technology, industry  
 Exhibition Road, South Kensington,  
 London SW7 2DD  
 Tel: (01) 589 6371
- MAIDSTONE** (Kent) Carriages  
 Tyrwhitt-Drake Museum of Carriages,  
 Archbishop's Stables, Mill Street,  
 Maidstone  
 Tel: (0622) 54497
- MANCHESTER** Science, industry of the North West,  
 North Western Museum of Science & textiles  
 Industry,  
 97 Grosvenor Street,  
 Manchester M1 7HF  
 Tel: (061) 273 6636
- NEWCASTLE-UPON-TYNE** Engineering, maritime, mining,  
 Museum of Science & Engineering, transport  
 Exhibition Park, Great North Road,  
 Newcastle NE2 4PZ  
 Tel: (0632) 20737
- NOTTINGHAM** Local industry, textiles (lace)  
 Industrial Museum,  
 Wollaton Hall, Courtyard Buildings.

Nottingham NG8 2AE

Tel: (0602) 284602

OXFORD

Museum of the History of Science,  
Old Ashmolean Building, Broad Street,  
Oxford OX1 3AZ

Tel: (0865) 43997

Scientific instruments

READING (Berkshire)

Museum of English Rural Life,  
Whiteknights Park, Reading RG6 2AG

Tel: (0734) 85123, ext 475

Farm and craft technology, rural  
industry

ST HELENS (Lancashire)

Pilkington Glass Museum,  
Prescot Road, St Helens WA10 3TT

Tel: (0744) 28882

Company museum,  
history of glassmaking

SALFORD (Lancashire)

Science Museum, Buile Hill Park,  
Eccles Old Road, Salford M6 8GL

Tel: (061) 736 1832

Coalmining, local industry

SHUGBOROUGH (Staffordshire)

Staffordshire County Museum,  
Shugborough, Stafford ST17 0XB

Tel: Little Haywood 388

Local industry, transport

STOKE BRUERNE (Northamptonshire)

Waterways Museum, nr Towcester

Tel: Northampton (0604) 862229

Inland waterways

STOKE PRIOR (Worcestershire)

Avoncroft Museum of Buildings,  
nr Bromsgrove, B60 4JR

Tel: Bromsgrove 31363

Museum of buildings

STREET (Somerset)

Clarks Shoe Museum,  
Street

Tel: (0458 4) 3131, ext 2681 & 2557

Company museum, footwear  
manufacture

- SUNDERLAND (County Durham) Restored railway station, local history  
 Monkwearmouth Station Museum,  
 North Bridge Street,  
 Sunderland  
 Tel: (0783) 7705
- Public Museum & Art Gallery, Maritime, local industry  
 Borough Road, Sunderland SR1 1PP  
 Tel: (0783) 70417
- SWANSEA Local industry  
 Industrial Museum of South Wales,  
 Victoria Road, Swansea
- SWINDON (Wiltshire) Great Western Railway  
 Great Western Railway Museum,  
 Faringdon Road, Swindon  
 Tel: (0793) 27211
- TELFORD (Salop) Open Air Industrial Museum,  
 Blists Hill Open Air Museum iron, coal, clay, the Iron Bridge  
 Coalbrookdale Museum & Furnace Site  
 Ironbridge Gorge Museum Trust, Church  
 Hill, Ironbridge, Telford, Salop TF8 7RE  
 Tel: (095 245) 3522
- TOWYN (Merioneth) Narrow-gauge railways  
 Narrow Gauge Railway Museum,  
 Wharf Station, Towyn
- WEST DEAN (Sussex) Open-air museum of buildings  
 Weald & Downland Open Air Museum,  
 Singleton, Chichester  
 Tel: Liphook 723104
- YORK Railways  
 Railway Museum, Queen Street,  
 York YO1 1HT  
 Tel: (0904) 53022

### 3 Industrial Archaeological Organisations

**ABERGAVENNY & DISTRICT STEAM SOCIETY**  
Secretary: 15 Elm Drive, Llanellen, Abergavenny, Mon

**ABERTAY HISTORICAL SOCIETY: IA SECTION**  
Secretary: 21 Strawberry Bank, Dundee DD2 1BH

**ANTIQUARIAN HOROLOGICAL SOCIETY**  
Secretary: 35 Northampton Square, Clerkenwell, London EC1

**ASSOCIATION FOR INDUSTRIAL ARCHAEOLOGY**  
Secretary: Church Hill, Ironbridge, Telford, Salop TF8 7RE  
Tel: 095-245 3522

**ASSOCIATION OF COUNTY COUNCILS**  
Secretary: 66a Eaton Square, London SW1W 9BH  
Tel: 01-235 5173

**ASSOCIATION OF DISTRICT COUNCILS**  
Secretary: 25 Buckingham Gate, London SW1E 6LE  
Tel: 01-828 7425

**ASSOCIATION OF METROPOLITAN AUTHORITIES**  
Secretary: 36 Old Queen Street, London SW1H 9JE  
Tel: 01-930 9861

**BASINGSTOKE IA GROUP**  
Chairman: 103 Maldive Road, Basingstoke, Hants

**BATH & CAMERTON ARCHAEOLOGICAL SOCIETY**  
Secretary: 61 Pulteney Street, Bath

**BATH UNIVERSITY: CENTRE FOR THE STUDY OF THE HISTORY OF TECHNOLOGY**  
Director: School of Humanities and Social Sciences,  
Claverton Down, Bath BA2 7AY

**BATLEY MUSEUM SOCIETY: IA GROUP**

Secretary: 16 High Cote, Riddleston, Keighley, Yorks

**BERKSHIRE ARCHAEOLOGICAL SOCIETY: IA GROUP**

Secretary: 2 Eldon Road, Reading RG1 4DH

**BIRMINGHAM & WARWICKSHIRE ARCHAEOLOGICAL SOCIETY: IA RESEARCH GROUP**

Secretary: Dept of Industrial Administration, University of Aston in Birmingham, Maple House, 158 Corporation Street, Birmingham 4

**BRADFORD ARCHAEOLOGY GROUP, IA SECTION**

Secretary: Bradford Industrial Museum, Moorside Mills, Moorside Road, Bradford BD2 3HP

**BRADFORD UNIVERSITY, IA UNIT**

Secretary: The University, Richmond Road, Bradford BD7 1DP

**BRISTOL INDUSTRIAL ARCHAEOLOGICAL SOCIETY (BIAS)**

Secretary: Hunter's Hill, Oakfield Road, Keynsham, Bristol BS18 1JQ

**BRITISH COUNCIL**

Director: 65 Davies Street, London W1Y 2AA

Tel: 01-499 8011

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Asst Secretary: 47 Belgrave Square, London SW1X 8QX

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**BRITISH TRANSPORT FILMS**

Melbury House, Melbury Terrace, London NW1

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66 Porchester Road, London W2

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**BUSINESS ARCHIVES COUNCIL**

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**CARNEGIE UNITED KINGDOM TRUST**

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## CHESTER &amp; DISTRICT IA SOCIETY

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Tel: 01-930 0914

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## COMMITTEE FOR NAUTICAL ARCHAEOLOGY

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Tel: 01-387 6052

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Secretary: 32 Russell Road, London W14

## CORNWALL ARCHAEOLOGICAL SOCIETY: IA SUB-COMMITTEE

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## COUNCIL FOR BRITISH ARCHAEOLOGY: GROUP 2: IA SECTION

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## COUNTRYSIDE COMMISSION

1 Cambridge Gate, London NW1 4JY

Tel: 01-935 5533

## COUNTRYSIDE COMMISSION FOR SCOTLAND

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Tel: 0738 27921

## CRAFTS ADVISORY COMMITTEE

Secretary: 12 Waterloo Place, London SW1

Tel: 01-839 5263

## CUMBERLAND AND WESTMORLAND ANTIQUARIAN &amp; ARCHAEOLOGICAL SOCIETY: IA COMMITTEE

Joint Secretaries: M. Davies-Shiel, Lilac Cottage, Lake Road, Bowness-on-Windermere, and Dr J. D. Marshall, Department of History, University of Lancaster

## DEPARTMENT OF THE ENVIRONMENT

Directorate of Ancient Monuments & Historic Buildings, 2 Marsham Street, London SW1P 3EB. Chief Inspector of Ancient Monuments & Historic Buildings, Fortress House, 23 Savile Row, London W1X 2AA

Tel: 01-734 6010.

See also Historic Buildings Council; National Monuments Record. Royal Commission on Historical Monuments

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Sectional Secretary: 48A Sandbed Lane, Belper, Derby

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Tel: Windermere 4444

## ENGLISH TOURIST BOARD

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Tel: 01-730 3400

## EUROPEAN ARCHITECTURAL HERITAGE YEAR, 1975

(United Kingdom Secretariat)

17 Carlton House Terrace, London, SW1Y 5AW

Tel: 01-930 0914

## EXETER IA GROUP

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## FAVERSHAM SOCIETY

Secretary: 42 Newton Road, Faversham, Kent

## FIELD STUDIES COUNCIL

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## FORFAR &amp; DISTRICT HISTORICAL SOCIETY

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## GEORGIAN GROUP

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Tel: 01-235 3081

## GLOUCESTERSHIRE SOCIETY FOR IA

Secretary: 6 & 7 Montpelier Street, Cheltenham

## 'GREAT BRITAIN' PROJECT

The British Centre, Quality House, Quality Court, Chancery Lane, London WC2  
(and Great Western Dock, Bristol). Concerned with SS *Great Britain*.

## GREATER LONDON IA SOCIETY (GLIAS)

Secretary: 69 St. Peter's Road, Croydon, Surrey, CR0 1HS

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United Kingdom and British Commonwealth Branch

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Tel: 01-636 5313-7

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Secretary: Dept of Archaeology, University of Southampton, SO9 5NH

## HIGHLANDS &amp; ISLANDS DEVELOPMENT BOARD

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Tel: 0463 34171

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## HISTORIC BUILDINGS BUREAU

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## HISTORIC BUILDINGS COUNCIL (SCOTLAND)

Secretary: 21 Hill Street, Edinburgh 2

## HISTORIC BUILDINGS COUNCIL (WALES)

Secretary: Welsh Office, Summit House, Windsor Place, Cardiff CF1 3BQ

## HISTORIC COMMERCIAL VEHICLE CLUB

1 Pembury House, Abbey Park, Beckenham, Kent

Tel: 01-650 2896

## HISTORICAL ASSOCIATION

Secretary: 59A Kennington Park Road, London SE11 4JH

Tel: 01-735 3901

## HISTORICAL METALLURGY SOCIETY

Secretary: Dept of Economic History, The University, Sheffield, S10 2TN

## HISTORICAL MODEL RAILWAY SOCIETY

Secretary: 18 Beverley Gardens, Great Woodley, Romsey, Hampshire, SO5 8TA

## HUDDERSFIELD IA SOCIETY

Secretary: 119 Coniston Avenue, Dalton, Huddersfield

## INDUSTRIAL STEAM PRESERVATION GROUP

Chairman: 146 Milner Close, Hunslet Grange, Leeds 10

## INLAND WATERWAYS ASSOCIATION

Gen Secretary: General Office, 114 Regent's Park Road, London, NW1

Tel: 01-586 2556, 2510

## INLAND WATERWAYS PROTECTION SOCIETY

Secretary: Gorrie-side, Cartledge Lane, Holmsfield, Sheffield, S18 5SB

Telephone: 0742 138352

## INSTITUTE OF ARCHAEOLOGY

Secretary & Registrar: University of London, 31-34 Gordon Square, London, WC1H 0PY

Tel: 01-387 6052

## INSTITUTE OF CHEMICAL ENGINEERS

Gen Secretary: 16 Belgrave Square, London, SW1

## INSTITUTE OF MARINE ENGINEERS

Secretary: Memorial Building, 76 Mark Lane, London, EC3

## INSTITUTE OF PATENTEES &amp; INVENTORS

Secretary: 207-8 Abbey House, Victoria Street, London, SW1

## INSTITUTE OF QUARRYING

Secretary: 62-4 Baker Street, London, W1

## INSTITUTE OF TRANSPORT

Secretary: 80 Portland Place, London, W1

## INSTITUTION OF CIVIL ENGINEERS

Secretary: Great George Street, London, SW1

Panel for Historic Engineering Works (PHEW): address above

## INSTITUTION OF ELECTRICAL ENGINEERS

Secretary: Savoy Place, London, WC2

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## NATIONAL COUNCIL ON INLAND TRANSPORT

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## NATIONAL FILM ARCHIVE

81 Dean Street, London, W1V 6AA

## NATIONAL HERITAGE: THE MUSEUM ACTION MOVEMENT

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## NATIONAL LENDING LIBRARY FOR SCIENCE &amp; TECHNOLOGY

Boston Spa, Yorkshire

## NATIONAL MONUMENTS RECORD (INCLUDING NATIONAL BUILDING RECORD)

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## NATIONAL RECORD OF INDUSTRIAL MONUMENTS

University of Bath, Claverton Down, Bath, Somerset

## NATIONAL REFERENCE LIBRARY OF SCIENCE &amp; INVENTION

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Secretary: 307 Spen Lane, Leeds, LS16 5BD

YORKSHIRE TOURIST BOARD

312 Tadcaster Road, York, YO2 2HF

Tel: 0904 67961

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The following is a selective list of books and pamphlets relevant to the general themes of industrial archaeology in Britain. The first sections relate to the chapter divisions of this book and are followed by regional works broken down under the same headings as in Appendix 1.

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- Baxter, B. *Stone Blocks and Iron Rails* (David & Charles, Newton Abbot, 1966). An account of the evolution of tramways in Britain, with a gazetteer of sites
- Coleman, T. *The Railway Navvies* (Pelican, 1968). A highly readable account which brings alive the men who built the railways.

- Ellis, H. *British Railway History*, two volumes (Allen & Unwin, 1954 and 1959). Volume 1 covers the period 1830 to 1876, volume 2 from 1877 to 1947. A most readable account of the development of the British railway system
- Journal of the Railway & Canal Historical Society* (published quarterly). Details of the Society and the *Journal* from the Secretary, 174 Station Road, Wylde Green, Sutton Coldfield, B73 5LE
- Lewis, M. J. T. *Early Wooden Railways* (Routledge, 1970). A detailed and comprehensive study of the earliest type of railed transport
- Morgan, B. *Railway Relics* (Ian Allan, Shepperton, 1969). An account of surviving railway civil and mechanical engineering remains in Britain with gazetteer
- Outley, G. *A Bibliography of British Railway History* (Allen & Unwin, 1965). A massive compilation of railway literature
- Rolt, L. T. C. *Isamhard Kingdom Brunel* (Longman, 1957, and Pelican, 1970). Not only the life of a great engineer but an outstanding biography in its own right
- Simmons, J. *The Railways of Britain: An Historical Introduction* (Routledge, 1961). A comprehensive general account of the development of railways in Britain
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- Transport History*. Journal published three times a year by Bratton Publishing, Edinburgh. Editor, Baron F. Duckham, University of Strathclyde. Covers all aspects of transport history

#### *Ports and Harbours*

- Bracegirdle, B. and Miles, P. H. *Thomas Telford* (David & Charles, Newton Abbot, 1973). Illustrates a number of Telford's harbour works
- Glynn, J. *Construction of Cranes and Machinery: A Rudimentary Treatise* (1854; reprinted Kingsmead, Bath, 1970). Useful work on small cranes frequently found on docks and canal wharves
- McNeil, I. *Hydraulic Power* (Longman, 1972). Covers many applications of hydraulic power but with considerable emphasis on harbours
- Mountfield, S. *Western Gateway* (Liverpool University Press, 1965). A history of the Mersey Docks & Harbour Board
- Sennett, R. and Oram, H. J. *The Marine Steam Engine* (Longman, 1915). The standard work

#### *Regional Publications*

Although some regional publications have been mentioned in the preceding subject bibliography, the following are concerned with industrial archaeology in specific

regional or local areas of Britain. Many contain gazetteers of sites. The most comprehensive, although by no means complete, is the *Regional Industrial Archaeology* series published by David & Charles. There are numerous gazetteers published as pamphlets, of which a selected sample is included. Information on a particular area and on the availability of specifically local literature can best be obtained through an appropriate industrial archaeological society (see Appendix 3)

#### Scotland

- Bracegirdle, B. and Miles, P. H. *Thomas Telford* (David & Charles, Newton Abbot, 1973). Many Scottish illustrations
- Butt, J. *The Industrial Archaeology of Scotland* (David & Charles, Newton Abbot, 1967)
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- Davies-Shiel, M. and Marshall, J. D. *The Industrial Archaeology of the Lake Counties* (David & Charles, Newton Abbot, 1969)
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- Atkinson, F. *The Great Northern Coalfield 1700-1900* (Durham County Local History Society, 1966)
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- Duckham, B. F. *The Yorkshire Ouse* (David & Charles, Newton Abbot, 1973)  
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 Singleton, F. *Industrial Revolution in Yorkshire* (Dalesman Publishing, Clapham via Lancaster, Yorkshire, 1970)

#### *The West Midlands*

- Copeland, R. *Cheddleton Flint Mill and the History of Pottery Milling, 1726-1900* (Cheddleton Flint Mill Preservation Trust, 1969)  
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- Chapman, S. D. *The Early Factory Masters* (David & Charles, Newton Abbot, 1967)  
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 Smith, D. M. *The Industrial Archaeology of the East Midlands* (David & Charles, Newton Abbot, 1965)  
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- Ashdown, J., Bussell, M. and Carter, P. *A Survey of Industrial Monuments in Greater London* (Thames Basin Archaeological Observers' Group, 1969). A gazetteer of sites  
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Laws, P. *Industrial Archaeology in Bedfordshire* (Bedfordshire County Council, 1967).

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Barton, R. M. *A History of the Cornish China Clay Industry* (D. B. Barton, Truro, 1966)

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- Minchinton, W. E. *The British Tinplate Industry* (Oxford University Press, 1957)
- Morgan Rees, D. *Mines, Mills and Furnaces* (National Museum of Wales, Cardiff, 1969)
- Thomas, W. G. *Amgueddfa, Bulletin of the National Museum of Wales, No. 10* (Cardiff, 1972). Preserving industrial sites in Wales

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*The index deals with general items, such as electricity, docks, bridges and so on. Only items of special interest are individually included by name eg Clifton Bridge. For specific sites attention is drawn to the gazetteer on pages 428-50.*

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